RECENT SEDIMENTATION IN NORTHERN CARDIGAN BAY, WALES

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CONTENTS

SYNOPSIS

Marine sediments in the shallow waters of northern Cardigan Bay, Wales, are dominantly fine-grained sands that have been well sorted by active tidal and longshore currents. Minor accumulations of bimodal deposits of sand and gravel are present near the sarns, and at the base of the eroding coastal cliffs. The bay deposits are composed of six common minerals (determined by X-ray analysis) : quartz, muscovite, chlorite, orthoclase, plagioclase, and calcite. Rarely, minor amounts of dolomite are present. Based on their gross mineral content, the deposits are classified as quartzose sands, with a few being subgreywackes, or sublithic sands. Petrographic thin section study of impregnated samples, utilizing an inclusive, empirical grain classification scheme, provides a method for reporting data on, and charting the distribution of, the several types of quartz and lithic fragments. Charted dispersal patterns indicate local sources along the coast, namely eroding exposures of glacial debris and sea-cliffs of slates and greywackes. Spectrochemical data for Al, B, Ba, Ca, Co, Cr, Cu, Fe, Ga, K, Mg, Mn, Na, Ni Pb, Sc, Sr, Ti, V, and Zr are reported (Tables III–VII), and their distributions in the bay sediments charted. Distribution patterns of certain elements associated with accessory minerals define zones of tidal currents, while elements related to aluminosilicates largely indicate the locations of eroding coastal exposures currently supplying detritus to the bay. Enrichment of Ca and Sr is indicative of bioclastic debris. These findings are supported by comparison of chemical data for nearby Welsh rocks (Table II). It is concluded that most of the bay sands are derived from coastal erosion sites and not from sources inland ; streams are not active suppliers of sand to the bay ; estuaries are being infilled from the sea ; net transport of sediment is northward inshore, but seaward, in part, offshore ; and that the present bay sands would have the desirable features of a reservoir rock if they were buried in the subsurface. Finally, the reported data and descriptions provide useful interpretive criteria for the recognition and correlation of ancient sediments deposited under similar conditions, as well as for detailed comparative studies of other Recent sediments.

I. INTRODUCTION

This report presents the results of a study of 262 sediment samples, collected from a portion of northern Cardigan Bay, Wales, and 26 nearby reference samples (253 sediment samples BM 1964, 88–340; 26 reference rock samples BM 1964, 341–366, and thin sections are housed in the sea floor collections of the British Museum Natural History). The area (Text-figs. 1, 2) is bounded by Sarn Wallog (near Aberystwyth) on the south and Sarn Badrig on the north. The western boundary is a north/south line through the West Prong light buoy at the seaward, or terminal end of Sarn Badrig; thus, the area is approximately 13 nautical miles wide and 23 nautical miles long. The eastern boundary is, of course, the shoreline, including the Mawddach and Dyfi estuaries (Text-fig. 2). A few samples were collected beyond the boundary-forming sarns and in several nearby rivers to provide an overlap with adjacent surveys currently in progress. Sampling profiles and stations were planned after study of available charts, but the final density of sample coverage was controlled partly by limitations of boat operation, which is hazardous near the sarns, and partly by the texture of the bottom as megascopically determined at each sample station.

This study is a contribution to the Cardigan Bay–Irish Sea Research Project of the University College of Wales, Aberystwyth. The Project was instituted in 1962 to provide for a comprehensive, continuing investigation of the sediments, fauna, oceanography and tectonic history of the southern Irish Sea. The present study of the sediments of Northern Cardigan Bay is a functional part of the programme and has the objectives of describing the sediments, in terms of their texture, composition, chemistry and optical petrography and of determining their distribution and dispersal. Standard sampling and laboratory techniques which are applicable, for the most part, to lithified sediments have been used. The results are mainly presented in a related series of charts, and the conclusions are based wholly upon the reported data (Tables III–VII).

Certain aspects of the research, e.g., microfauna, accessory minerals and Pleistocene history are being investigated by others. Although detailed provenance studies are being conducted at Aberystwyth, it is desirable to report the mineralogical and spectrochemical data (Tables I and II) for several reference rock samples collected, mainly, from outcrops adjacent to the study area. These are included for

TABLE I

WELSH REFERENCE ROCKS: MINERALOGY (X-RAY %)

(Mi. mica; Chl. chlorite; Qtz quartz; Or. orthoclase; Pg. plagioclase; Cal. calcite; Dol. dolomite; Phys. phyllosilicates; Fels feldspars; Cas carbonates)

BM. No.	Grid Ref.	Geological formation	Rock type	Mi.	Chl.	Qtz	Or.	Pg.	Cal.	Dol.	Phys	Fels	Cas
1964, 349	SN/618962	U. Llandovery	Shale	22	41	28	1	8	—	—	63	9	—
1964, 350	SH/740019	U. Llandovery	Shale	26	34	32	2	6	—	—	60	8	—
1964, 351	SH/795031	U. Llandovery	Arenite	8	30	48	—	11	—	3	38	11	3
1964, 352	SN/687952	U. Llandovery	Siltstone	27	36	29	2	6	—	—	63	8	—
1964, 355	SN/606888	U. Llandovery, Aberystwyth Grits	Shale	25	40	29	2	4	—	—	65	6	—
1964, 361	SN/592859	U. Llandovery, Aberystwyth Grits	Arenite	23	38	30	1	6	—	2	61	7	2
1964, 353	SN/667939	L. Llandovery	Arenite	4	12	70	—	14	—	—	16	14	—
1964, 364	SH/662165	Cambrian, Dolgelly Beds	Arenite	—	7	36	25	32	—	—	7	57	—
1964, 365	SH/694184	Cambrian, Ffestiniog Beds	Arenite	42	26	21	1	10	—	—	68	11	—
1964, 341	SH/719198	Cambrian, Penrhos Shale	Shale	27	31	33	1	8	—	—	58	9	—
1964, 346	SH/682407	Cambrian, Penrhos Shale	Arenite	36	29	27	—	8	—	—	65	8	—
1964, 343	SH/728230	Cambrian, Vigra Flags	Arenite	28	34	28	—	10	—	—	62	10	—
1964, 360	SH/625157	Cambrian, Vigra Flags	Arenite	20	21	24	—	35	—	—	41	35	—
1964, 359	SH/621166	Cambrian, Gamlan Flags	Arenite	30	32	28	—	10	—	—	62	10	—
1964, 347	SH/598326	Cambrian, Barmouth Grits	Arenite	17	17	42	—	24	—	—	34	24	—
1964, 358	SH/617170	Cambrian, Barmouth Grits	Arenite	7	17	51	—	25	—	—	24	25	—
1964, 348	SH/596323	Cambrian, Manganese Shale	Shale	22	33	37	—	8	—	—	55	8	—
1964, 344	SH/728230	Cambrian, Rhinog Grits	Arenite	18	14	52	—	13	3	—	32	13	3
1964, 356	SH/613176	Cambrian, Rhinog Grits	Arenite	11	16	51	—	22	—	—	27	22	—
1964, 345	SH/274335	Cambrian, Dolwen Grits	Arenite	31	27	28	—	14	—	—	58	14	—
1964, 342	SH/732217	In Cambrian	Dolerite	4	49	19	—	24	—	4	53	24	4
1964, 354	SN/667939	In L. Llandovery	Quartz vein	—	—	100	—	—	—	—	—	—	—
1964, 357	SN/581999	Quaternary, in Boulder Clay	Arenite	17	27	46	3	7	—	—	44	10	—
1964, 362	SH/716171	In Cambrian	Diabase	5	29	4	—	30	—	—	34	30	—
1964, 363	SH/675142	Ordovician, Lower Basic Series	Rhyolite	—	23	31	—	46	—	—	23	46	—
1964, 366	SH/705166	In Cambrian	Granophyre	48	23	17	2	10	—	—	71	12	—

Table II

Welsh Reference Rocks; Chemistry (Spectrographic)

B.M. No.	Al_2O_3 %	B ppm	Ba ppm	Ca %	Co ppm	Cr ppm	Cu ppm	Fe_2O_3 %	Ga ppm	K %	Mg %	Mn ppm	Na %	Ni ppm	Pb ppm	Sc ppm	Sr ppm	Ti ppm	V ppm	Zr ppm
1964, 349	21·4	57	340	0·12	27·5	93	66·0	8·50	28·4	2·12	1·34	960	1·25	54·4	1	35·6	85	5150	113	139
1964, 350	24·2	74	410	0·07	30·0	98	52·0	8·00	29·6	2·52	1·30	1380	1·25	73·0	1	38·5	117	6000	124	156
1964, 351	10·5	29	150	0·82	25·2	62	45·0	7·65	12·7	0·53	1·20	1800	0·86	52·0	63	23·0	73	3600	66	200
1964, 352	17·3	65·5	470	0·04	20·3	118	26·5	7·40	27·0	1·83	0·93	640	1·11	50·0	80	33·0	98	6200	111	117
1964, 355	35·7	86	390	0·14	14·0	139	56·5	8·10	28·6	2·27	1·84	720	1·22	55·0	4	143·0	130	7000	138	160
1964, 361	25·0	68	280	0·83	20·1	102	66·0	7·70	21·5	2·18	1·23	660	1·16	52·0	4	28·7	104	5300	113	117
1964, 353	4·3	38	140	0·17	13·0	31	12·4	3·90	5·4	0·36	0·33	1100	0·88	24·0	2	9·4	96	3900	39	510
1964, 364	10·2	5	560	0·24	—	—	1·0	3·25	24·0	3·32	0·11	510	2·22	5·3	10	46·5	119	1380	6	535
1964, 365	22·4	63	910	0·18	12·2	126	29·6	6·25	30·0	2·64	0·90	174	1·55	48·0	19	33·0	149	6250	110	132
1961, 341	23·0	41	350	0·19	24·7	120	35·5	8·60	22·5	1·75	1·55	320	1·19	60·6	2	35·8	136	5750	96	126
1964, 346	26·0	44	290	0·48	29·2	104	73·0	7·55	29·0	2·12	1·10	175	1·27	65·0	8	32·0	171	6150	116	110
1964, 343	21·5	36	790	0·30	15·4	117	55·0	5·95	29·4	2·65	1·24	325	1·45	56·0	1	34·0	109	5600	99	124
1964, 360	10·9	23	315	0·22	8·7	54	20·6	4·50	14·7	1·05	1·00	740	1·38	29·0	2	15·4	92	3650	68	164
1964, 359	20·6	43	570	0·18	30·0	76	69·0	6·90	23·4	2·00	1·08	3100	1·18	51·0	11	30·0	84	4950	89	130
1964, 347	11·8	18	455	0·72	5·9	49	14·4	3·85	14·6	1·77	0·66	1180	1·44	15·2	1	21·7	86	4200	71	123
1964, 358	6·0	7	140	0·34	4·9	31	1·9	4·00	8·7	0·49	0·47	940	1·26	11·3	4	10·3	84	2750	51	390
1964, 348	13·2	50	440	0·23	66·0	85	83·0	8·20	21·6	1·90	0·90	8400	1·00	68·0	11	24·0	63	4050	76	142
1964, 344	5·3	21	220	0·83	9·2	35	9·4	4·29	11·7	1·12	0·37	390	1·07	14·1	1	12·6	85	3000	57	258
1964, 356	5·2	7	190	0·10	9·6	41	2·7	4·20	9·4	0·52	0·48	1030	1·24	14·9	1	—	82	3950	65	290
1964, 345	15·2	25	1050	0·83	21·0	81	52·5	6·30	20·0	2·10	1·62	420	1·37	36·0	1	40·0	111	5600	110	161
1964, 342	26·5	12	195	5·55	35·0	76	96·0	9·40	24·2	0·46	3·30	750	1·23	42·0	2	44·5	345	6400	220	78
1964, 354	0·2	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20	—	—	—
1964, 357	15·7	57	475	0·10	16·2	86	50·0	6·62	24·0	1·61	1·20	720	1·08	48·5	41	19·8	89	4700	87	270
1964, 362	21·2	23	120	8·10	58·0	340	63·0	9·48	19·6	0·60	3·10	760	1·17	80·0	—	34·7	242	6200	198	50
1964, 363	14·8	6	335	0·48	7·6	31	1·0	4·84	20·8	0·49	0·62	540	2·50	18·6	6	17·0	99	3200	59	122
1964, 366	36·5	75	2980	0·11	6·2	146	7·6	4·89	34·8	2·80	1·01	195	1·56	12·2	1	41·5	237	6650	114	154

chemical comparisons, and are not intended to represent, or to suggest, a basis for establishing overall provenance-sediment relationships. Such is beyond the scope of the present study.

There are no published results of Recent sediment investigations for this area. Blundell, King & Wilson (1964, p. 47) report that, on the basis of seismic evidence, some rocks beneath Cardigan Bay may be " a sequence of late Mesozoic or Tertiary clays and sands ". Their research has been confined to geophysical investigations, and only indirectly relates to the surface sands. Haynes (1964) made brief mention of the sand texture for this area. Adams, Haynes & Walker (1965) reported boron data for Dyfi estuary sediments.

II. REGIONAL SETTING

Although the present study is restricted to a limited inshore area in northern Cardigan Bay (Text-fig. 1), the influences of bathymetry, physical oceanography and coastal geology beyond it establish, in part, the regional picture and, thus, are discussed below as are the local environmental influences.

Bathymetry. Text-fig. 1 shows that the sea bottom slopes away from the Welsh coast until it reaches a depth of slightly over 50 fathoms (300 feet) at the bottom of St. Georges Channel. The depth contours are approximately parallel to both the coast and to the north/south axial salient of St. Georges Channel itself. The overall gradient between the Welsh coast and the 20 fathom line, a contour delimiting the seaward margin of Cardigan Bay (H.O. Publication 145, 1951), is some 4·5 feet per nautical mile. The only notable gradients in Cardigan Bay proper are the sharp drop-off to about five fathoms immediately adjacent to parts of the coast, usually within one mile of the shore; the relatively steep gradient surrounding the sarn ends, and finally the entrenched trough, defined by the 20 fathom line, extending northeastward into Tremadoc Bay. The " trawling ground ", a slightly deeper (12 fathoms) depression south of Aberystwyth, is locally important as a site of mixed clay and sand deposition.

Beyond the 20 fathom line, in the Irish Sea proper, the bottom slope shows a slightly increased gradient between 30 and 40 fathoms, but otherwise it remains fairly constant seaward. The deepest part of the Irish Sea (50 fathoms) in this region forms a narrow north-trending depression from 5 to 15 nautical miles in width.

In directing attention to the bathymetric features of the study area itself (Text-fig. 2), it is seen that the only pronounced features present are the three sarns. If one neglects their local influence on bottom topography, the inshore province along the coast of Wales, between the sarns, is one of gradual increase of depth seaward. Nevertheless three minor features of the bottom should be mentioned. The first is the depression at the landward end of Sarn Badrig. This depression is scoured by the strong, nearshore current which is initiated by overflow (at flood tide) from Tremadoc Bay. It is important as an active transport passage for detritus from Tremadoc Bay. The second is the shoaling zone which is in alignment with the lobate contours extending from the northeast corner of this survey to near the seaward termination of Sarn Bwch. On the basis of these bathymetric contours alone, one may visualize a definite zone of active sedimentation extending from the northeast corner of the survey to some several kilometres west of Sarn Bwch. The third is an open trough developed at the outer end of Sarn Bwch; it is delimited by the ten fathom line. This bathymetric depression may explain the relatively

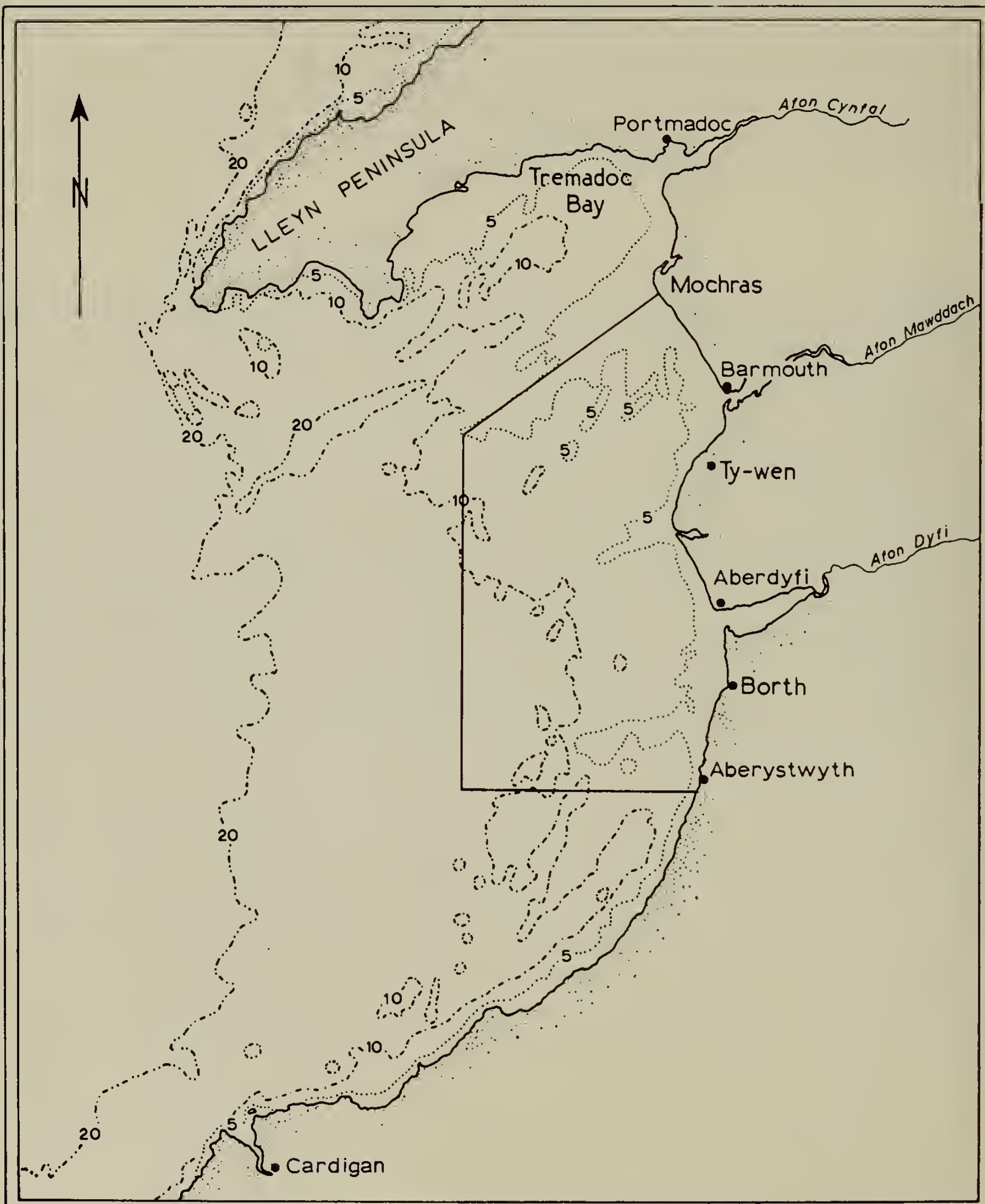

FIG. 1. Chart showing location of the study area in relation to the principal geographic and bathymetric features of the southern Irish Sea area. Contours in fathoms.

high velocity tidal current which is encountered off the end of Sarn Bwch, for although of modest dimension, it may force considerable water into a relatively narrow passage along the bottom there.

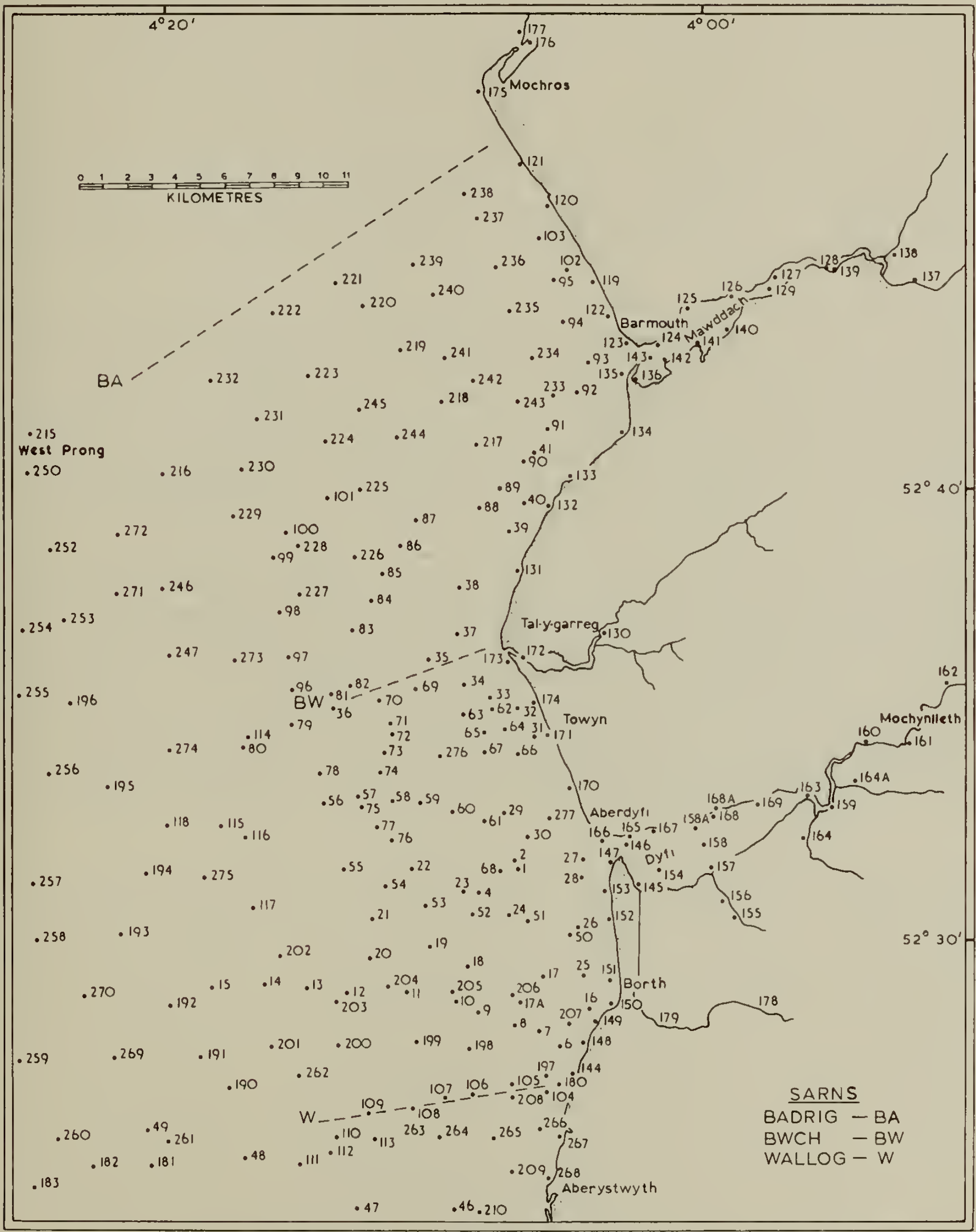

FIG. 2. Location of samples taken from Cardigan Bay and the local rivers.

Climatic factors. Of the various climatic factors, only seasonal gales, rainfall and temperature are of consequence in the present study. Gales with a velocity of 38 miles per hour and upwards, are common over the Irish Sea and are known to be the cause of heavy seas along the Welsh coast. The average number of gales (H.O. Pub. 145, 1951, p. 14) in this area was 35·3 per year for the years 1876/1915, of which 27·7 occurred during the months of October to March and 7·6 during the period of April to September. Of the 35·3 gales per year, 14·5 were southwesterlies, and 10·3 were northwesterlies. Winds from other directions may occasionally reach gale force, but they are short-lived, less common and are considered unimportant in this study. The importance of the westerly, winter gales cannot be over-emphasized, because the erosive action of the storm breakers causes most of the coastline modification and subsequently furnishes the bulk of the detritus now entering the bay.

The region, as a whole, experiences moderately heavy rainfall, e.g., the annual rainfall average for the years 1881/1915 at Aberystwyth was 46 inches (H.O. Pub. 195, 1951). As the topography of the land controls, to some extent, the rainfall from the moist wind off the Atlantic, the mountainous Welsh coast experiences a higher proportion of rain than those areas of modest relief nearby. Heavy rainfall along the Welsh coast accounts for the lower-than-normal salinities encountered within the first 2 or 3 miles of the coast (Dr. John Haynes, personal communication).

Coastal features between Aberystwyth and Mochras. Greywackes are exposed along the shore between Aberystwyth and Borth (Pl. 2, fig. 1), and have been studied in detail (Wood & Smith, 1959), particularly their sedimentary structures. These authors report that, on the basis of thin section study, the greywackes are poorly sorted, i.e., containing a considerable amount of fine material with the grit, and contain quartz (75 to 80% of the material which could be resolved in thin section), feldspar, muscovite and carbonate minerals, mostly in sand and fine sand sizes. The cliffed shoreline between Aberystwyth and Borth is being actively eroded, and the lithic fragments occurring at the base of the cliffs are predominantly composed of, and immediately derived from, the Aberystwyth Grits.

A storm-beach, composed of pebbles and sand with a beach of medium-grained sand, extends from Borth northward for some three miles where it terminates at the Dyfi Channel. Behind the Borth beach an estuarine development of marsh and open sand flats extends up the Afon Dyfi Channel from the river mouth. These sediments texturally resemble those offshore, and grass, in part, has aided in stabilizing this major accumulation of sand.

From the town of Aberdyfi northward towards Towyn, the coastline consists of a moderately wide beach backed, in part, by sand dunes. The coastal section here is aggrading, and sand dunes behind the beach have become stabilized and grass covered. In the vicinity of Towyn, however, the coast is being actively eroded. Outcrops along the coast in this area are mixed gravel and sand beds, boulder clays and peat deposits. As these relatively unconsolidated deposits are easily eroded by high seas, erosion of the coast at Towyn is proceeding rapidly, and this site is an important source for much of the detritus now being delivered to the bay. A coastal section of boulders commences near Towyn, in the vicinity of Sarn Bwch, and extends northward, in part, around the point at Tal-y-garreg. A small portion of the coast northwest of Tal-y-garreg is exposed bedrock of slates and thin, dense sandstones. A fresh exposure of boulder clay, at the head of a boulder beach, outcrops about a mile north of Sarn Bwch point (Pl. 2, fig. 2). The boulders eroded from the glacial debris in this area have formed a natural rip-rap, which partially inhibits erosion of the remaining boulder clay and, in a few places, vegetation is growing over the boulder clay. Nevertheless, field evidence suggests that some erosion is still taking place—perhaps modified by the protection Sarn Bwch affords from southwesterly seas—and that the finer clastics are being delivered to the sea. The coast between Ty-wen and Station 134 is reasonably stable, as suggested by field evidence. From Station 134, south of the town of Barmouth, a long storm-beach of mixed sand and pebbles extends northward to the Mawddach estuary mouth, where it curves inward and parallels the channel.

Much the same setting is found for the Mawddach estuary as that found for the Dyfi, i.e., behind the protective storm-beach, an area of fine sand, partly covered by *Spartina* grass, extends up the estuary. In the upper estuary, local areas of marsh deposition occur on both sides of the channel, and, in places amongst the marsh sands, argillaceous silt is found as a very thin surface deposit.

From the town of Barmouth, a relatively wide beach extends northward continuing to, and forming, the outer edge of Mochras point. For the most part, this coastal zone is one of sand accumulation resulting from northward transport accompanying inshore tidal currents and wave induced, littoral drift.

Field study of the river deposits did not reveal active transport of fine sand. The transport of fine sand, under normal river flow, is apparently negligible at the present time. To say that the rivers may have once carried an abundance of fine sands cannot be established on the basis of present field evidence, and, thus, the past sediment transport history of Welsh rivers is unknown. On the other hand, it is probable that clay is transported by the streams, in flood, possibly in the form of muscovite and chlorite flakes, but the high energy regime of this part of Cardigan Bay prohibits its deposition.

Local geology. The general geologic structure and rock types of the area adjacent to northern Cardigan Bay have been described by Keeping (1881), Jones (1912, 1956), Jones & Pugh (1935), Cox (1925), Cox & Wells (1920, 1927), Jehu (1926), Challinor (1949), Wood & Smith (1959), Mohr (1959), and Matley & Wilson (1946). Additional studies are listed by Thomas (1896) and Bassett (1961). The majority of the exposed rocks in the area are slates, shales and arenites, all of which are folded and faulted to varying degrees, and in many places associated with hydrothermal (vein) quartz. In a few places, crystalline rocks are exposed, the most important types being granophyres, dolorites, rhyolites, and several other volcanic varieties, but by far the greatest number of exposures are those of slates and greywackes. Geochemical and mineralogical data for 26 of these rocks are given in Tables I and II.

Boulder clay covers much of the countryside along the coast, but with the exception of coastal exposures at Towyn and north of Sarn Bwch, it is not being extensively eroded and, indeed, is usually grass covered. Pleistocene and subsequent transgressive reworking is undoubtedly important to the Irish Sea sediments as a whole, particularly in the distribution of coarse clastics, but until more is learned of the mineralogical and chemical nature of the boulder clays, and their relative distribution and stratigraphy, and until long bottom cores are studied, no realistic historical interpretations can be made.

Salinity and Temperature. Salinity determinations have been made on water samples collected seasonally both from surface estuarine waters, and from surface and subsurface waters offshore by Dr. John Haynes. His investigation has shown that salinity varies in the Dyfi Estuary between 1‰ and just over 36‰, whilst inshore waters, of northern Cardigan Bay vary in salinity between 29‰ and 34‰; the former value being typical of the mixed waters just seaward of the estuary mouths during periods of ebb flow. Data for "typical" offshore waters, at least seaward for some 15 miles, show a gradual but definite increase in salinity up to 34‰. This figure is lower than open Atlantic salinities of about 35‰, and is the result of fresh water entering the sea through the numerous rivers along the Welsh coast. While salinity is primarily of biological importance, it may influence some trace element concentrations in detrital marine clays, particularly boron (Walker & Price, 1963), and perhaps in the phyllosilicates in lithic fragments as well.

Temperature data for part of the outer Cardigan Bay region are reported by Lee (1960) in his recent study of the Irish Sea. Some serially collected data have been acquired by the Aberystwyth staff, but only for the estuarine and inshore waters in the southern part of the present study area. From a series of surface measurements in March 1953, the 6·5° C. isotherm was found to extend in a north/south direction some 17 km. off the Welsh coast, and very near Station 118 of the present survey. The 7° C. isotherm parallels the 6·5° C. isotherm about 30 km. offshore, and the highest temperatures (7·5° C.) were recorded in the middle of the Irish Sea. Temperatures on the Irish side were somewhat warmer than for the Welsh side, 7·0° C. being an average (Lee, 1960, p. 17). During the autumn of 1962, the author and Dr. John Haynes measured sea surface temperatures for the area between Sarn Wallog and Sarn Bwch. In the month of October a high value of 14° C. was recorded, which decreased to 7° C. in early December. Littoral water measurements were made at Aberystwyth throughout the severe winter of 1962–63, and the lowest temperature recorded was 0·7° C.

Waves and currents. In general, the effective fetch for winds from the west is about 80 to 90 nautical miles. For southwesterlies, considerably more fetch is available as the opening of St. Georges Channel is in line with the open Atlantic. In this instance, effective fetch may exceed 200 nautical miles, although refraction of long-period waves by St. David's Head, Pembrokeshire, diminishes the direct line of wave parallelism into Cardigan Bay. For northwesterly winds approaching from greater than about 300° (true), the effective fetch is greatly shortened by the Lleyn Peninsula and even more so by Sarn Badrig. Thus, prevailing winds from the west and from the southwest, with longer fetches, initiate the highest waves encountered along the coast of northern Cardigan Bay. Inasmuch as the prevailing sea, as well as the gale force winds, is from the west and southwest, most of the waves striking the shore provide a net transport of nearshore water in a northerly direction and immediately adjacent to the coast. In the case of northwesterly winds, the effective fetch, as previously mentioned, is only some few tens of miles and, as such, wind waves striking the coast from this sector may initiate weak, wave-induced littoral drift to the south. Sarn Badrig acts as a natural wave trap for northwesterly wind waves coming across Tremadoc Bay ; thus, only those waves with a reasonably short period or relatively small orbital geometry will finally break on the shore between Sarn Bwch and the vicinity of Barmouth. Likewise, the combined effect of the Lleyn Peninsula, Sarn Badrig and Sarn Bwch strongly diminishes the size of waves approaching from the northwest. Superimposed upon the westerly wave trains is a complex pattern of wave refraction caused by the pronounced submarine topography of the three sarns.

Considering this study area from an environment and energy viewpoint, the sarns probably provide natural wave traps for all reasonably long-period waves striking the coast obliquely. Bottom sediments in the lee of oncoming wave trains are not wave agitated below a depth controlled locally by the height of water over the sarn. This assumption is supported by textural evidence, for the deposits offshore from Borth are some of the finest grained clastics found in the area. The problem of interpreting waves and their refraction patterns in the light of sediment transport mechanics is made extremely difficult by the complex tidal currents. In general, however, three observations may be made regarding the energy system in northern Cardigan Bay. First, the net transport of nearshore detritus is to the north, but detritus may locally be transported southward for short periods of time when the prevailing wind is from the northwest and the tidal current is ebbing. Second, the fetch presented by the entire width of the Irish Sea is such that gale force winds cause a heavy surf along the coast, even though refraction by the sarns reduces or spreads out the available energy. Third, the area is a " high energy environment " with strong tidal currents, drift and surf.

The only detailed information available on the direction and magnitude of tidal currents in the northern part of Cardigan Bay is that published by the Admiralty Hydrographic Dept. (1962), and observations, descriptive in nature, made at Aberystwyth. The latter were restricted to the estuary mouths and to the three sarns.

The major axis of offshore tidal currents, both at flood and at ebb, is a north/south one for the region between Sarn Wallog and Sarn Bwch. In the area between Sarn Bwch and Barmouth, the axis of the tidal currents parallels the coast and is oriented in a northeast/southwest direction. However, tidal current vectors on H.O. Chart No. 4454 (1934) show a tidal current direction almost normal to Sarn Badrig on the flood tide, which would make it northwesterly, but a due south orientation on the ebb tide. This shift in direction for the two tidal phases presents complications in developing a rigid interpretation of currents for the northern area of the survey, and until adequate measurements are made at sea, preferably from an anchored vessel, all conclusions must be considered as provisional ones. Fine grained sand seems to be transported over the sarns at shoaling depths, since it is entrapped among the seaweed attached to boulders and cobbles along the axis of Sarn Wallog and Sarn Badrig. The presence of this sand is not surprising as strong currents were observed in the immediate vicinity of each sarn, in fact, some currents accelerated from 3 to 5 knots over the crest of the sarns. These submarine topographic features restrict the flow so that the cross sectional area normal to the transport direction is diminished, and there is a concomitant increase in the velocity of the current. Inasmuch as the surface velocities for the north/south tidal currents have a mean of almost one knot at maximum flood, it is not unreasonable to estimate three to fivefold increases in velocity over bathymetric highs.

One area in particular should be discussed, for it shows a major tidal current influence on the dispersal of sands. This is in the right angle corner formed by the axis of Sarn Badrig and the Barmouth/Mochras coast. A depression found very near the coast is suggestive of a zone of strong bottom current scour and inshore sediment transport. Admittedly, coastal drift in this area provides for the northward transport of sand, however, ebb tide and possibly overflow, caused by water pushed into Tremadoc Bay by southwesterly gales, creates a strong net transport nearshore and over the sarn in a southerly direction. Fine sand is, in fact, transported over the sarn and to the south as shown by the dispersal patterns for several grain types.

According to Hjulstrom's (1939) curve the tidal currents in the northern part of Cardigan Bay are of sufficient strength to remove clay size and fine silt clastics from the area, and, there is in general, little opportunity for clay detritus to accumulate in abundance with the offshore sands, especially since no major depressions are present within this area.

III. TREATMENT OF SAMPLES

In the laboratory surplus water was removed by decantation or by a rubber syringe. The moist sample was then placed in a drying oven for a period of approximately 48 hours at a temperature of 100° F., or slightly below. Every effort was made in handling the samples to avoid removing the constituent sea water which adhered to the grains. Sedimentologists, notably Goldberg & Arrhenius (1958), have suggested that the constituent, or interstitial, water must be considered as a part of the lithosphere rather than as a part of the hydrosphere. This is particularly important concerning those trace elements which may occupy grain surface sites.

A representative portion of between 80 and 100 grams of sediment was spread on a sheet of paper and all unbroken shells above 4 mm. in size were removed. Small shell fragments were considered a constituent part of the deposit. A portion was weighed and then passed through a set of British Standard sieves on a Ro-Tap shaker. Using both 3-cycle semi-logarithmic and arithmetical probability paper (Chartwell Nos. 5535 and 5571), cumulative curves were drawn for all analyzed samples (Milner, 1962 ; Folk, 1961). Gravel and cobble samples were measured using machinist's calipers, weighed and the resulting data graphed to provide cumulative curves (Krumbein & Pettijohn, 1938).

In order to provide a basis by which Cardigan Bay samples could be petrographically compared and to delineate dispersal zones in the bay, the writer studied thin sections of the various samples, excepting some gravels. The procedure for preparing thin sections of Recent sediments has been published elsewhere (Moore & Garraway, 1963). At least 330 grains were identified in each thin section (van der Plas, 1962); while for some slides more than 500 grains were counted (Weber & Middleton, 1961, p. 247).

The sample portion held aside for X-ray diffraction was further divided into three parts using a small Jones splitter. This material was then ground for 25 minutes in a power driven agate mortar and pestle, and sieved through a 325 mesh A.S.T.M. sieve. Approximately 0·5 gram of the sieved powder was back loaded, i.e., with the " face " side against a clean, smooth glass slide, into a standard Phillips aluminium sample holder. Three mounts were made of each sample.

A Phillips N.A. wide-range, Geiger counter, X-ray diffraction unit and a Brown " Electronik ", fast response, chart recorder were employed. Operating conditions were as follows: copper target, 40 kV, 17 MA, Ni filter, 1° diverging and converging slits, scanning (goniometer) speeds of 1° and 2° minute, recorder chart speed of 1 inch/4 minutes, and the rate meter set at a scale factor of 8, multiplier at unity, and time constant at 4 seconds. For mineral identification, one mount was analysed at a goniometer speed of 1°/minute from 4° to 66° 2θ. The diffraction maxima or peak positions were read to the nearest 0·01° in the range from 4° to 34° 2θ. Mineral identification was made by comparing the unknown (sample) diffractogram with known diffractograms of previously analysed mineral standards, and by comparison with the *d* spacings listed in the American Society of Testing Materials X-ray Powder Data File. Quantitative mineral data were obtained by subjecting each of the three mounts to diffraction analysis from 4° to 36° 2θ at a goniometer speed of 2°/minute. The characteristic diffraction maxima of each of the minerals were measured in tenths of an inch above the background, as recorded, and the mean taken for the series. These data were then multiplied by mineral intensity percentage factors previously obtained from the standards analyses and, finally, normalized to total 100% of the minerals identified.

Compositional mineral abundances obtained in the above manner very closely approximate the true or actual mineral percentages. The difference is due to variations in the degree of crystallinity, and to slight variations in the mass absorption coefficients between the standards and the sample material. Furthermore, variation can result from preferred particle orientation, although the latter can be minimized by mounting procedures. In order to avoid confusion between 14 Å chlorites and the vermiculite and montmorillonite groups, both heat treatment and addition of vapourized ethylene glycol were standard procedures. For comparative purposes, reference rock samples containing montmorillonite (from the Isle of Wight) were subjected to diffraction analysis along with the bay samples.

The portion of each sample retained for analysis by emission spectroscopy was ground to the fineness of a silt-clay powder, using a Braun 6-S grinder fitted with Coors Co. " Alumina " brand grinding discs. A small portion, about one gram, was then transferred to an agate mortar and hand ground to powder fineness. This portion was dried at 110° C. for 24 hours. Duplicate fractions of 25 mg. portions were packed in United Carbon Co. type 3417 anode preforms. The cathodes were specially fabricated from $\frac{1}{8}$-inch diameter graphite rod, and were purified by refluxing with dilute aqua regia for three days and with distilled water for two days. The loaded preforms were stored in plastic holder-boxes within a vacuum dessicator until arced.

All samples were prepared in the above manner and were subjected to a total energy burn (arcing) in a Jarrel-Ash Co. Model 7100, 3·4 metre Ebert emission spectrograph with a dispersion of 5 Å/mm. in the first order. Operational adjustment was set at 19 amps, 220 volts d.c. when short circuited across the electrodes. Eastman Kodak III-o spectrograph plates were used and developed with Eastman Kodak D-19 developer. Comparisons were made with W-1, G-1, and with special standards previously developed by W. L. Hall of the Texaco Inc. Laboratory expressly for sedimentary geochemical interpretations. Pd and In were used as internal standards and a standard step-filter system permitted determinations to be made of selected major elements. All readings were made on the same machine, a console Jarrell-Ash Co. model 2100 microphotometer, and no valves or other component parts were changed during the reading of the plates.

IV. TEXTURE

In addition to " grain size ", statistical measures provide a comparative basis for detecting subtle textural variations within a single class interval, relating composition to texture, establishing texturally controlled geochemical associations, defining the degree of size dispersion, or sediment type mixing, and charting textural trends related to environmental energy and to provenance influence. Textural definition is nevertheless not an end in itself.

Statistical measures. Based upon data obtained from sieve analysis, the cumulative curve for each sample was drawn and analysed as suggested by Folk (1961). The cumulative curve is the best graphic form from which all statistical measures are obtained, and it is considered as the beginning point in modern statistical description. Those measures selected by the author for use in this study are as follows: first quartile (Q_1), third quartile (Q_3), median diameter (Md), sorting (So), skewness (Sk), 16 percentile intercept (ϕ 16), 84 percentile intercept (ϕ 84), median in phi units (ϕ M or ϕ 50), graphic mean (ϕ *Mz*), graphic standard deviation ($\phi\sigma$ g), and standard deviation interval mean (ϕ MI). These terms, their meaning and derivation, are reviewed in detail by Folk (1961).

Textural classification terms. Using the statistical measures of ϕ *Mz* and the first and third quartiles (Q_1 and Q_3), equivalent Wentworth (1922) and Niggli (Pettijohn, 1957) nomenclature have been determined for each sample. The terms have been used to prepare charts depicting the textural facies and to provide textural classifications (Text-figs. 3, 4, 5). The restricted two-component nature of the bay deposits, namely sands and gravels, eliminated the effective use of such ternary component classifications as were reviewed by Shepard (1954).

Grain size distribution based on ϕ Mz measures. Using the reported measure ϕ *Mz*, a contoured chart was drawn for the Cardigan Bay deposits (Text-fig. 3).

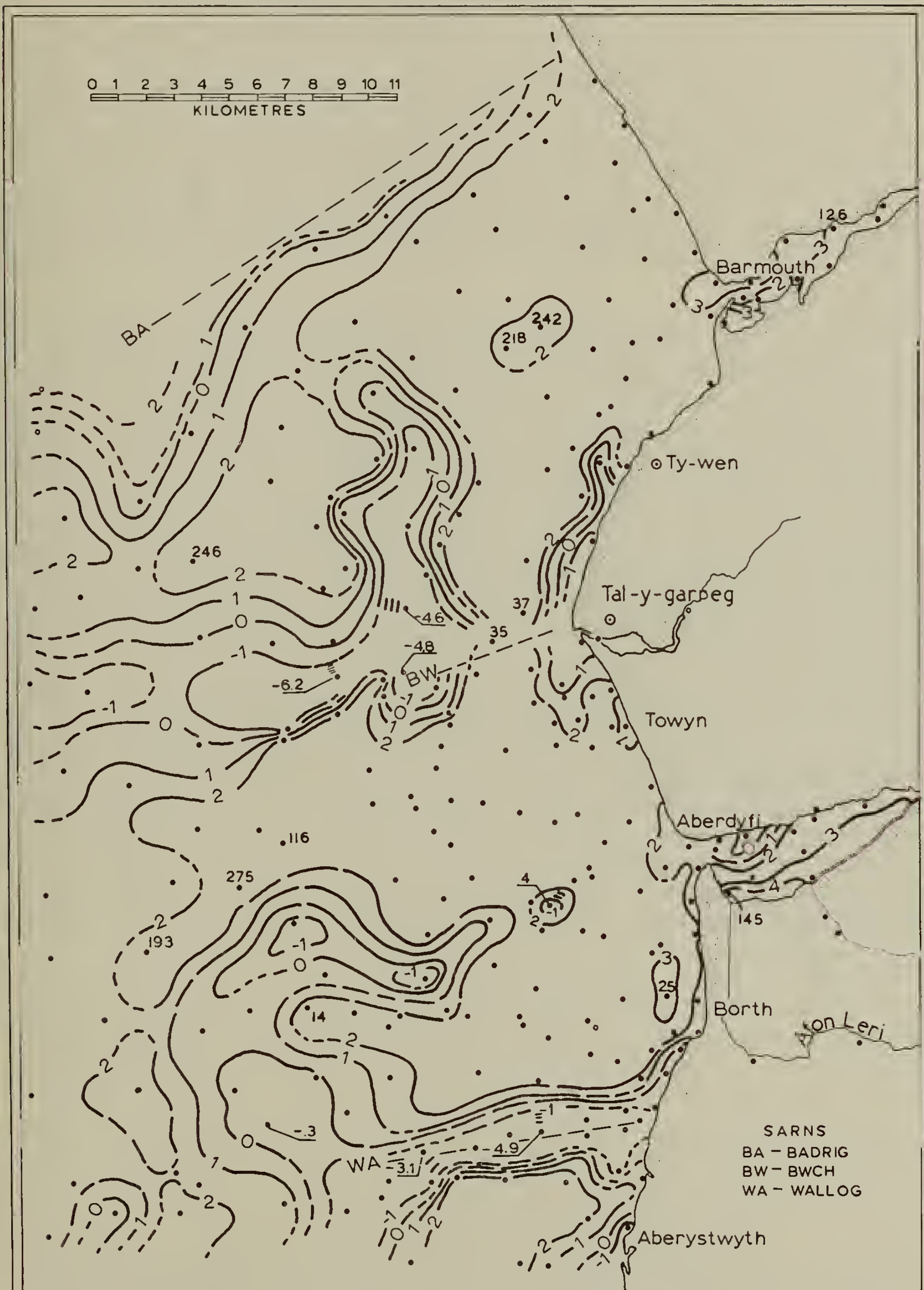

FIG. 3. Textural chart based on graphic mean size determinations (ϕ Mz). Contour interval 1ϕ.

The contour interval of one phi unit was purposely selected in order to conform with Wentworth grade scale limits. The most noticeable area of single-class size distribution is the major region of fine sand (ϕ 2 to ϕ 3), which, in this part of Cardigan Bay, is located inshore and along the coast. This deposit is remarkably uniform in texture, averaging about 2·4 ϕ *Mz*, and encloses only two sites of coarser sediments: a deposit of lag gravel in the vicinity of Station 4 and a small patch of medium sand (ϕ 1·8, ϕ 1·9) in the area around Stations 218 and 242. The only deposit of very fine sand in the bay area proper is found within the major sand body in the area around Station 25, about 1·5 km. off the Borth beach, an area partially protected by Sarn Wallog.

Fine sand extends just north of Sarn Wallog across the shoaling area to the south side of Sarn Bwch. The northward extension of this sand is from the vicinity of Station 37 completely across the, more-or-less, flat shelf bottom off Barmouth to the base of the steep, south side of Sarn Badrig. It also extends approximately 15 km. seaward to near Station 14, and as a southwesterly zone through Stations 116, 275, and 193. In the northern area the tongue extends seaward through Station 246. The fine sand on both sides of Sarn Bwch, which separates Stations 35 and 37, appears to come within a few yards of the ridge of the sarn at this point, and, in fact, fine sand is transported over the sarn in this area. Safety precautions during boat operations limited sampling in the immediate sarn area, and consequently the actual width of the connection cannot be established. Petrographic observations suggest that the fine sand is compositionally similar on both sides of Sarn Bwch.

Other than the major deposits of gravel and cobbles constituting the sarn ridges themselves, the only coarse deposits in the area are the tongue of coarse debris extending northward from Sarn Wallog, two similar coarse deposits extending northward and westward from the end of Sarn Bwch, and the nearshore and littoral deposits north-west of Tal-y-garreg, and along the base of the cliffs south of Borth. (High beach and storm-beach gravels were not sampled for this study.)

The estuaries are largely filled with fine and very fine sands, and rarely silt: the latter type being restricted to two sites (Stations 124 and 126) on the north side of the Mawddach estuary, and one small area (Station 145) where the Afon Leri enters the Dyfi estuary.

Descriptive textural facies. As an alternative presentation of the basic ϕ *Mz* measures, a chart was drawn using descriptive nomenclature equivalent to the ϕ *Mz* values (Text-fig. 4). The designated Wentworth term for the ϕ *Mz* measure of each sample was plotted and all similar, adjacent textural types were grouped as contiguous sedimentary facies. This system permits a somewhat broader interpretation as sharp changes in facies may be charted without adhering to rigidly controlled numerically based contour trends. From a study of the chart, it is seen that the major fine sand area is represented much the same as when using ϕ *Mz* (numerical) measures, so are the gravel zones associated with the sarns. The statistically designated medium and coarse sands, however, are interpreted somewhat more smoothly, i.e., they exhibit better continuity and more natural distribution.

If one accepts the implications of Hjulstrom's (1939) curve for detrital transport and sedimentation, there is no reason why some textural classes should not be distributed without intermediate sizes between them. Thus, the deposition of medium sand on the north side of Sarn Wallog and the deposition of fine sand on the south side do not seem unrealistic cases at all. In fact, the interpretative, but not necessarily statistical, pattern of depositional facies is more clearly brought out in this chart based on descriptive grouping. In the broadest sense, that of establishing the major clastic facies, the patterns based on the descriptive chart (Text-fig. 4) agree with those outlined on the $\phi\ Mz$ chart (Text-fig. 3).

Distribution of depositional types based on Niggli terms. In order that mixed, or poorly sorted, textural types may be charted and compared with others, a chart based on the Niggli nomenclature (Text-fig. 5) is presented. The Niggli scheme uses the equivalent terminology of quartiles at the Q_1 and Q_3 points (Pettijohn, 1957, p. 26). A binomial designation is obtained when the quartile intercepts fall in separate, widely spaced classes. For extremely bimodal deposits the scheme is desirable; however, for essentially arenaceous deposits (a single Niggli class), the scheme is not definitive.

From study of the Niggli chart (Text-fig. 5) it is apparent that for sand sizes, resolution is not possible. In other words, the specific texture of the sands is not discernible, and the entire area of fine, medium and coarse sands is charted as one large sand facies extending from the shore to the westward limit of study. On the other hand, deposits associated with the sarns and with littoral deposition between Aberystwyth and Borth exhibit distinct class bimodality and are the only bay deposits which are so defined by the Niggli system. The textural character of Cardigan Bay deposits is (expressed in its broadest terms) a major sand area broken only by the gravels and sandy gravels of the sarns, and the previously noted tongues of coarse sediment. By using the Niggli scheme as a basis for establishing the textural framework, we are able to illustrate the dominantly sandy nature of the Cardigan Bay deposits in a very striking manner, and also show that the coarse sandy sediments are, in fact, largely mixtures of sand and fine gravel. The three classification systems ($\phi\ Mz$, Wentworth and Niggli) provide mutually compatible results, namely, the bottom sediments of Cardigan Bay are essentially fine sands with some development of gravelly deposits associated with the sarns and with the eroded cliff area, and some very limited development of accretionary silty sediments in the estuaries. The Niggli system has, however, the added feature of showing the locations of bimodal deposits.

Importance of the size classes. The finest sand sizes (2·5 to 3·0 ϕ) are distributed mainly on the inshore shallow bottom, within approximately 10 km. of the coast, and in the estuaries. In the northern part of the area, fine sands (2·5 to 3·0 ϕ) are found in the region off Eglwys Llanaber, and just off the estuary mouth at Barmouth. These findings coupled with the charted medium and coarser sands, suggest that for this area along the Welsh coast there is, in general, increasing grain size with increasing distance from the shore. This finding, particularly in relation

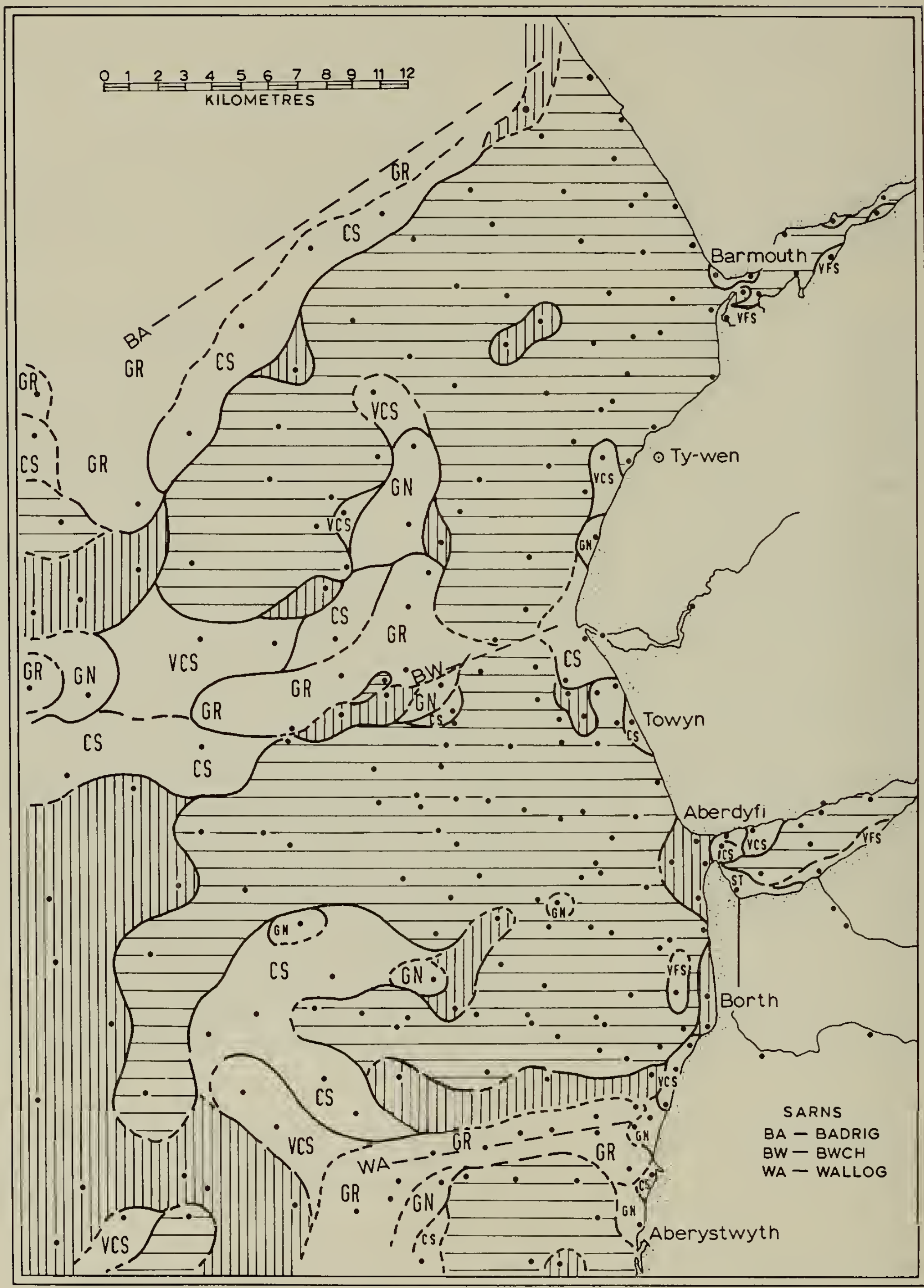

FIG. 4. Chart of grouped textural facies (Wentworth, based on ϕ *Mz* measurements). Fine sands are shown by horizontal lines, medium sands by vertical lines, coarse sands by CS, very coarse sands by VCS, granules by GN, gravel by GR, very fine sands by VFS, and silt by ST.

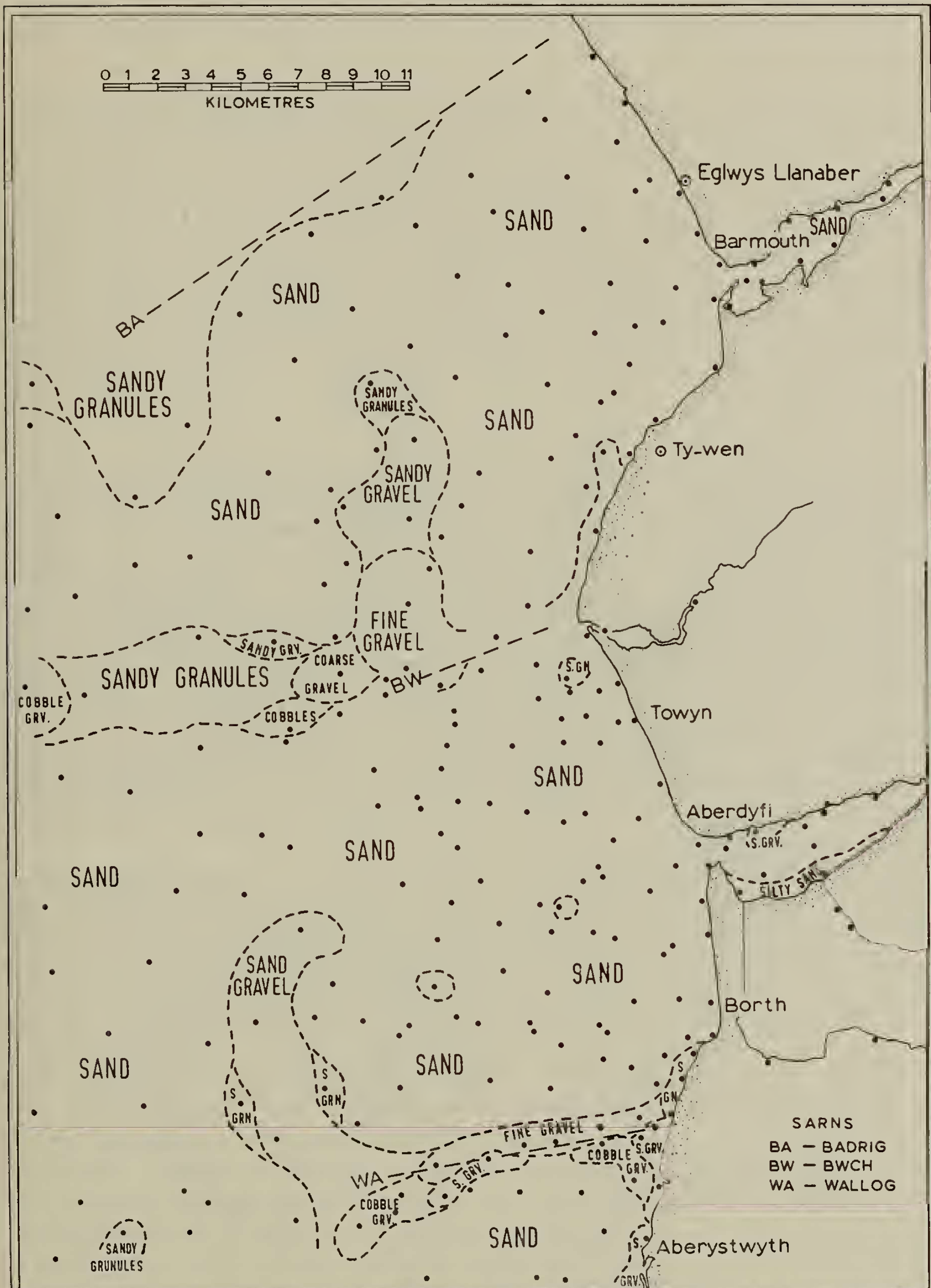

FIG. 5. Chart of sediment texture using Niggli nomenclature.

to contemporary studies of other Recent sediments, is significant (Shepard, Phleger & van Andel, 1960).

Predominance of the ϕ 2–ϕ 3 interval (0·12 to 0·25 mm.) grains in the bay suggests that a reasonably stable current energy and sediment dispersal system prevails. The ϕ 2 class of fine sand has been found as a common constituent of shallow Recent marine deposits in several other parts of the world, and it may, in fact, be the best adjusted (to physical environment) textural class of all inshore Recent marine sands, cf. Shepard *et al.* (1960). Stride (1963) reports that the sea level (and presumably the energy relationship) for the United Kingdom has been relatively stable for the past 6,000 years. This length of time should be sufficient for establishing normal dispersal pattern relationships between the tidal currents and the available detritus in the inshore area of the shelf, including Cardigan Bay. Therefore, a balance between source, tidal current energy, texture, and dispersal of the fine sands probably exists in Cardigan Bay.

Sorting of the deposits. Sorting, or " dispersion ", is a statistically derived measure, and need not necessarily be related to the textural size measures. However, in the study of inshore Recent marine sediments, sorting has been found to vary in accordance with grain size (Hough, 1942 ; Krumbein & Aberdeen, 1937 ; Stetson, 1938). This is also true for the Cardigan Bay deposits. From Text-fig. 6, it is clear that there are two major sediment types based on their characteristic So values ; the large area of fine sand between the sarns, which possesses So values below 1·25 and, as such, exhibits excellent sorting, and the coarser grained mixed sands and gravel deposits associated with the sarns and coastal erosion areas. Some of the fine sand at stations in the inshore waters just off Borth exhibit truly exceptional sorting (So): e.g., Stations 7 (1·06), 10 (1·08), 17A (1·08), 18 (1·09), 28 (1·09) and 68 (1·09). These stations are all within the finer ranges of the ϕ 2 to ϕ 3 deposits found there, and suggest a zone of sediments very well adjusted to the present-day current-energy system.

One of the limitations of any contoured chart is that the contacts between major facies are suggested to be transitional. This is not always substantiated in the field, and it is probable that the change from well sorted sediments to an adjacent area of poorly sorted sediments is an abrupt one. This became apparent during review of the data, as very few stations had sorting indices (So) between about 1·40 and 2·00. Reference to the excellent sorting trends in the fine sands and the poor sorting in the coarser sands and gravels, further established this facies relationship. Fine sands with low So values, such as Stations 6 (1·20), 207 (1·13) and 16 (1·24) parallel the rocky coast just south of Borth, and are only one km. seaward from a coastal zone of mixed gravel, cobbles and sand. The facies contact there is sharply defined, based on charted statistical measures as well as Marconi echograms. The northward-extending, curving-shoreward zone of poorly sorted deposits (Stations 190, 191, 192, 262, 201, 117, 202 and 20) just north of Sarn Wallog, is surrounded entirely by fine sands with excellent sorting values, all below 1·25 So. The contact between these two types is sharply defined, although the environmental mixing of sizes is obvious.

FIG. 6. Charted sorting values (Trask *So* measures).

Pronounced So gradients occur in the area north of the terminus of Sarn Bwch. Stations 228 (5·04) and 100 (1·22) are, in fact, only a fraction of a km. apart. The transition from well sorted fine sands to poorly sorted coarse deposits approaching Sarn Badrig is particularly sharp, and on one sampling profile (Stations 217–221), the sandy bottom was found to extend right up to the base of the sarn cobbles and gravel; this observation is based on echograms and on check samples taken as close to the sarn as the vessel could safely be manoeuvred.

With the exception of Stations 146 (1·75) and 167 (5·59), all samples from the two estuaries were found to be well sorted and predominantly fine sands. Indeed, all estuary values are below 1·20 So, including two important Stations: 163 (1·12) at the head of the Dyfi estuary and 139 (1·08) at the head of the Mawddach estuary. The upstream river deposits, on the other hand, were only fair to poorly sorted, regardless of their reported grain size.

$\phi\sigma$ g as a measure of sorting. To check the validity of the charted sorting pattern in the bay as determined by So, a chart (not figured) was prepared using the standard deviation ($\phi\sigma$ g) measures for the various stations. Inasmuch as $\phi\sigma$ g is based on more of the cumulative curve, this value is considered a good criterion for evaluating the So contoured chart, as well as for charting dispersion. As with the So (Trask index) chart, the major fine sand areas are also outlined as regions of best sorting. Within the area defined by the 0·50 $\phi\sigma$ g contour, a secondary region of exceptionally well sorted fine sand was located parallel to the coast, and about 4 km. offshore from Borth.

Even with an expanded coverage of the cumulative curve, no pronounced differences were noted in the distribution pattern of the poorly sorted deposits. The rapid facies change from well sorted to poorly sorted sediments became more noticeable, particularly in such areas as the inshore deposits from off Towyn northward to off Ty-wen, and in the sarn-associated deposits bounded by the 2 ϕ *Mz* interval. Estuarine deposits are found to be as well sorted using $\phi\sigma$ g as when using So values. In all, no change is made in the basic sorting plan by the use of $\phi\sigma$ g.

Intra-measure relationships. It is clear from Text-fig. 7, where ϕ *Mz* is plotted against $\phi\sigma$ g, that with rare exceptions, the best sorted deposits are those in the fine sand class. In fact, careful inspection shows that the best sorting is found in the middle range of the ϕ 2 interval where $\phi\sigma$ g values as low as 0·15 and 0·20 are reported. With increasingly larger grain size, even within the ϕ 2 interval, there is a corresponding decrease in sorting.

The medium-sands, 1 to 2 ϕ *Mz*, have a mean $\phi\sigma$ g value of about one unit, while the coarse and very coarse " sands " exhibit very poor sorting. There are few data for granule and gravel sediments, but the largest size gravel samples show an indication of approaching reasonably fair sorting, with a mean of just over 1 $\phi\sigma$ g. This last observation suggests that for some of the gravel deposits, there is, at least partial dynamic equilibrium within the physical energy environment. As can be seen from the chart, the poorest sorting is found in the coarser sands, while the best sorting is found in the finer sands. Paucity of data for ϕ *Mz* values below 3·0 precludes establishing significant trends for the very finest grained deposits.

The most pronounced variations in skewness are found in the coarse and very coarse sands. Since cumulative curves of the fine sands are almost symmetrical, there is no preferred tailing-off of the curve in the defined limits for them. From about the upper range of medium sands through the very coarse sands, Sk values show a decided skewness with asymmetry tailing-off in the coarser fractions. However, for those deposits having ϕ *Mz* values near ϕ 1, the skewness is toward the finer fractions.

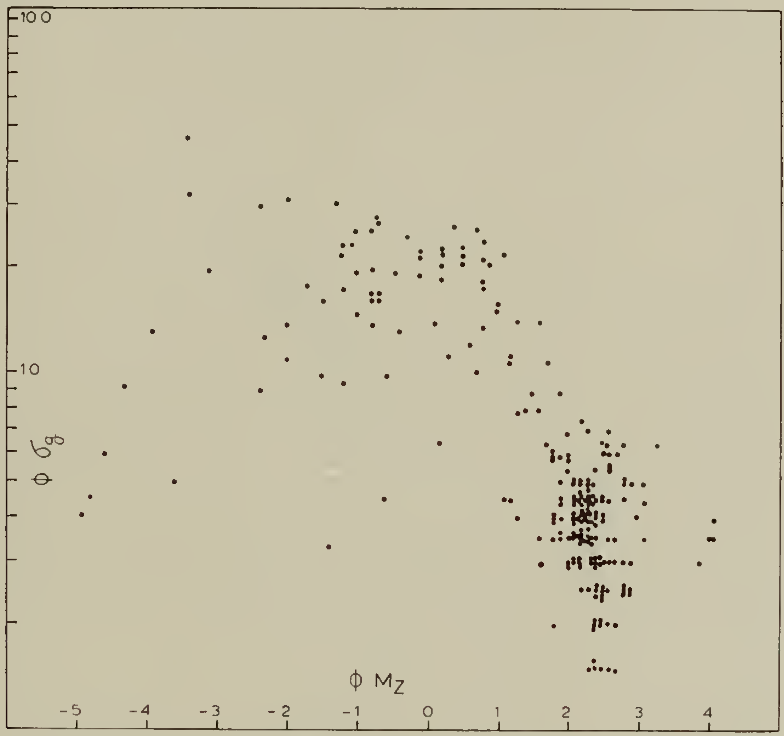

FIG. 7. Correlation of grain size (ϕ *Mz*) with sorting or dispersion ($\phi\sigma$ g.). Note that the fine sands are the best sorted ones.

The correlation of ϕ *Mz* with ϕ M50, the mid-point datum, (Text-fig. 8) suggests that while there is a good linear relationship for the fine and very fine sands and silts, the coarser classes do exhibit scatter. Most of the coarser interval values vary from the complementary ϕ *Mz* point by about one ϕ-unit. Of the entire suite of samples, only a few would be grossly misclassified if their textural nomenclature were based solely on Md (ϕ M50). In practice, of course, most workers reporting Md usually report corresponding So values, which would signal the reader to watch for size dispersion and, thus, possible size term discrepancies. It is suggested, therefore, that using caution regarding the coarse sand Md values, comparisons can be made between these ϕ *Mz* classified deposits and others classified solely on the basis of ϕ M50 (Md) data. Similarly, Gripenberg (1934, p. 52) said, " The median alone is a very good single characteristic of a sediment ". In short, since Cardigan

Bay fine sands are very well sorted, the median value may be used with confidence, when making comparisons.

Summary discussion on texture. The deposits of this part of Cardigan Bay consist of well sorted fine sands, and poorly sorted coarse (gravelly) sands, although some few gravel deposits are well sorted. The finest sizes of the 2–3 ϕ *Mz* interval are located close inshore, while the coarser grained sands are found farther seaward. Texturally, there is no trend suggesting that fine sand is being delivered to the bay through the estuaries. The fine sands and some gravel/cobble deposits are in equilibrium with the prevailing environmental energy regime.

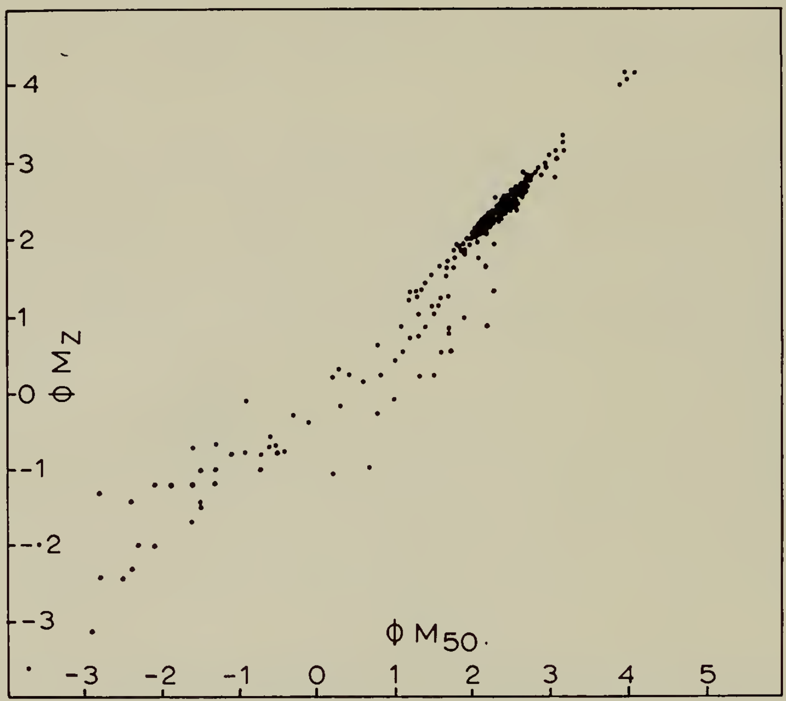

FIG. 8. Correlation of ϕ *Mz* with ϕ M50. For the fine sands it makes little difference whether ϕ *Mz* or ϕ M50 values are reported even though the former statistic is based on three points on the cumulative curve, and the latter on only one. While ϕ *Mz* is obviously more desirable, the median diameter provides a good index of size for most bay sediments.

The bay deposits may be described equally well using quartile measures, as by using ϕ based measures. For general comparisons, the size measures of ϕ *Mz*, ϕ MI and ϕ M50 (Md) are interchangeable, thus permitting textural comparisons with other similarly sorted marine deposits for which Md values alone are reported. The writer suggests, however, that the more modern usage of such measures as ϕ *Mz* and $\phi\sigma$ g are to be preferred over quartile based terms in reporting textural descriptions of Recent sediments.

Spencer (1963) in a critical review suggests that all deposits are made up of one, or more, of three basic grain-size populations : gravel, sand and clay. Accordingly, coarse sands and granule populations and silt populations are virtually non-existent as single genetic types, and their presence is accounted for by resolving a bimodal mixture into a single statistical entity, even if the curve does not exhibit apparent bimodality. Further, under conditions of high energy, little or none of the clay will be deposited, and the median, over a limited range, will serve as an indicator of the physical energy of the depositional environment. While it is too soon to determine how much of Spencer's population mixing concept will prove acceptable, and more data are needed to establish it on a firm empirical basis, to establish its validity is of paramount importance to economic geologists in their exploration for sandstone petroleum reservoirs. Likewise, sedimentologists, in their investigation and interpretation of Recent clastics and clastic rocks, should find his concept particularly useful for interpreting environmental energy systems. The present study appears to confirm the mixing concept; indeed, the conclusions reached in the present study have been tempered by our knowledge of Spencer's findings.

In general, the sand facies in northern Cardigan Bay present no difficulty in charting, or in defining their textural nature. However, the coarse sands and the very coarse sands, charted according to $\phi\ Mz$ measures, must be considered for what they are, i.e., mixtures of sand and either granules or gravel. Reference to Text-fig. 4, the chart of textural facies, shows very coarse sands and coarse sands extending northward from the seaward end of Sarn Wallog. If we were to attempt an environmental interpretation for this particular area (St. 190, 191, 192, 201, 15 and 202) based only on the representation provided by the chart, the suggested energy-sediment relationship would not be particularly important, the reason being that the bottom current energy needed to transport coarse and very coarse sands and that needed for fine and medium sands is much the same (Hjulstrom, 1939). Indeed, slightly less current (for transportation) is needed for the coarse sand according to the Hjulstrom curve. However, in considering the same area, but in the light of the Niggli scheme (Text-fig. 5), it is readily apparent that bimodal deposits of sand/granules, and sand/gravels are present. If we accept Folk's (1961) observation that the presence of even a small amount of gravel is significant indication of increased energy, then we must conclude that the mixed sand and gravel deposits extending northward from the end of Sarn Wallog are transported northward by relatively strong tidal currents. Moreover, considering the large amount of gravel present (29·4% at Station 190, for example), it is suggested that tidal currents are three times, or more, stronger in the mixed gravel and sand zone than outside it. This linear extension of coarse deposits appears to be related to a dispersal pattern whereby coarser deposits are removed from the end of the sarn, or transported around the sarn, and then carried northward and mixed with sand.

In the middle part of the present survey and west of Sarn Bwch, a similar situation exists. There, very coarse sand, according to the $\phi\ Mz$ chart (Text-fig. 3), is more realistically termed sandy gravel, and sandy granules in keeping with the Niggli scheme (Text-fig. 5). A similar relationship is also reported for very coarse sands and granules, and the sandy granules and sandy gravel in the region north of Sarn Bwch in mid-bay.

These examples are few in number and bimodal deposits constitute a small areal portion of the bay floor ; nevertheless, they are critical indicators of the high energy bottom current regime. The present data are such that the sarn source interpretation is not without an alternative. Careful study of the reported textural data and the charts suggests that the granule and larger size fragments are most probably derived from the erosion of the outer ends of the sarns, but it is possible that a part of the granule/gravel fraction of the mid-bay bimodal sediments may be material transported around the sarns from an ultimate source somewhere along the southern bay coast.

V. OPTICAL PETROGRAPHY

(*a*) *Petrographic classification of grain types*

After studying the thin sections of bay deposits as a whole, and ascertaining the common grain-types an empirical system of nomenclature was devised. This was done mainly because quartz studies (Krynine, 1940 ; Tuttle, 1952 ; Folk, 1961 ; Blatt and Christie, 1963) suggest that a given quartz type may originate from more than one kind of rock, for instance quartz with undulating extinction may be igneous, metamorphic, or reworked sedimentary in origin. For quartz the writer has chosen a binomial system adapted from Folk's (1961) scheme, and this has been combined with other minerals, in a classificatory scheme without genetic implications. Such an approach is well suited to the petrographic study of Recent sands because it allows dispersal charts to be drawn without needing a prior provenance study to establish those types which might be expected offshore, and it provides a flexible framework in which new types, particularly those with inclusions may be added. Detailed descriptions of the various grain categories, and examples of their use in provenance interpretations are to be found in Folk (1961) and Todd & Folk (1957)

Quartz was assigned to one of fifteen types in addition to secondary quartz overgrowths; the latter, a special type, is set off from the others. A binomial designation was used in which the first term was based on the characteristic extinction of the grain, and the second term was based on the presence or absence of inclusions, and the kind of inclusions when present.

In the present study, six extinction types are used in quartz classification :

1. *Straight extinction.* It is defined as simultaneous extinction of all parts of the grain, i.e., the grain is " darkened " uniformly (cf. BM 1964, 173 & 174).
2. *Slightly undulose extinction.* A definite, but broad, extinction shadow is observed to move across the grain, usually requiring up to five, or slightly more, degrees rotation of the stage (Folk, 1961, p. 71), cf. BM 1964, 99 & 287. *N.B.* The grains are randomly orientated.
3. *Strongly undulose extinction.* This type of extinction usually requires somewhat more than five degrees (up to 20° in some cases) of stage rotation for the extinction shadow to move from one extremity of the grain to the other. In practice, one easily recognizes strongly undulose extinction by the pronounced, narrow linear shadow which sweeps across the grain. In this extinction class, as in the previous two, reference is made to a single sand grain in crystallographic continuity (cf. BM 1964, 130 & 286).
4. *Semi-composite extinction.* In this category, as well as in the two which follow, reference is made to detrital fragments of quartz composed of two or more crystals, i.e., polycrystalline. Here the fragment is composed of joined, contact-to-contact sub-grains, which possess very

close optical orientation. As the stage is rotated, each grain becomes extinct in progressive order across the fragment, with extinction being straight, or only very slightly undulose for each grain. The sub-grain contacts within the fragment are not crenulated, and the extinction shadow does not cross grain boundaries within the fragment (cf. BM 1964, 100 & 102).

5. *Composite extinction.* This category includes fragments composed of two or more sub-grains, or crystalline individuals, with grossly different, usually irregular extinction. There is no preferred pattern ; extinction occurs first in one grain, then in another, randomly across the fragment. Borders of the grains within the fragment are not crenulated, and the extinction of each individual is straight, or only very slightly undulose (cf. BM 1964, 172 & 282).
6. *Composite metamorphic extinction.* This classification type includes polycrystalline fragments which exhibit strongly undulose extinction. In most cases the extinction shadow is pronounced as it sweeps across the fragment. Most fragments possess sub-grains with crenulated contacts, but this is not an absolutely necessary criterion for classification.

The second criterion for empirically classifying quartz grains is the nature of the included material, i.e., vacuoles, small crystals of other minerals, etc. While, in theory, the number of variables of this sort appears to be large, in practice only a few inclusion types are found in any one region. Such was found to be the case for the sands in the northern part of Cardigan Bay, where only four inclusion types occurred in sufficient numbers to provide statistically reliable counts. Preliminary study of the thin-sections revealed inclusions of vacuoles, microlites, rutile needles and chlorite flakes. It was obvious, too, that many of the grains, in fact the majority at some stations, did not possess inclusions and, thus, were categorized as " clear " (cf. BM 1964, 95 & 98). Common inclusions found in the Cardigan Bay sands are as follows :

1. *Vacuoles.* These are small liquid filled chambers, usually globular in shape and which appear to be brownish in colour. In most instances, the vacuoles are spatially distributed in a plane, or several planes, throughout the grain. Under medium power magnification, the vacuoles appear as linear traces, but subsequent inspection under high power magnification reveals their planar distribution. Some quartz grains possess vacuoles which are scattered randomly through the grain. Such types are moderately common (cf. BM 1964, 236 & 252).
2. *Microlites.* These are, by present definition, all mineral grains within the quartz fragment, except chlorite and rutile needles. Some variation was observed in the types of included minerals, but tourmaline, opaque unknowns and zircon, as ultra-small, euhedral crystals were commonly noted. Other minerals were rarely present (cf. BM 1964, 89 & 134).
3. *Fine* (*rutile*) *needles.* Inclusions of very fine, hair-like needles of rutile are found in some quartz grains. The extremely small size of these crystalline inclusions is a useful clue to their identity, and in this study rutile needles and the descriptive term " fine needles " are used interchangeably (cf. BM 1964, 158 & 276).
4. *Chloritic inclusions.* Small flakes of chlorite were observed in a few grains, but such inclusions are not common. Care must be taken in establishing that the chlorite is actually within the fragment (cf. BM 1964, 104 & 197).

Although detrital quartz formed the bulk of most sand samples other grain types are considered important constituents of the inclusive classification, these being as follows :

1. *Secondary quartz.* Several different types of grains, usually quartz, very rarely feldspar, were observed with secondary overgrowths of quartz, in optical continuity and euhedral in form (cf. BM 1964, 270 & 277).

2. *Carbonate fragments.* All calcareous grains have been assigned the collective designation of " carbonate fragments ". Only rarely were lithic carbonate rock fragments identified, and these were largely restricted to pebble deposits. The importance of this category is that it provides data for estimating, albeit roughly, the amount of carbonate material added to the sediments by biological processes in this particular marine environment (cf. BM 1964, 248 & 259).
3. *Arenites.* This category includes all rock fragments derived from sandstones and siltstones (cf. BM 1964, 152 & 222).
4. *Slate.* All shale, slate and phyllite fragments are grouped under this single petrographic classification. The small grain size of the majority of the bay deposits makes such assignment a necessity, for while a small grain can be determined as a lithic fragment composed chiefly of phyllosilicate minerals, little else about the original rock can be established (cf. BM 1964, 107 & 222).
5. *Crystallines.* Although certain of the crystalline rock types were readily identifiable in granules and in large sand grains, absolute type identification within the fine sand sizes was found to be limited to the occasionally encountered granophyre fragment. It was found, however, that even in small grains the general crystalline rock nature could be determined with reasonable assurance even though a specific clan name could not be assigned. Under such circumstances, *all* crystalline rock fragments were assigned to this common category (cf. BM 1964, 198 & 307).
6. *Feldspar.* Inasmuch as feldspathic grains most commonly occurred in sizes smaller than the host, or quartz, fraction, thus creating some difficulty in both statistical counting and type identification, it was decided to assign all feldspathic grains to one common group. X-ray diffraction data, also reported, are considered to provide a more accurate determination and measurement of the feldspars ; furthermore, classification schemes, such as Pettijohn's (1957), require only that total feldspar be pole assigned (cf. BM 1964, 180 & 273).

Counts of the several grain types were normalized, and relative percentage values were assigned to each classification category. Although counts were originally recorded for the various quartz extinction types with microlites, fine needles and chlorite flakes as inclusions, the totals for each of these three categories were subsequently grouped. No attempt was made to determine accessory minerals or rare grain types.

(*b*) *Dispersal of grain types and vectors*

Using petrographic data obtained from grain counts, dispersal charts for the various grain types were drawn and studied. Such graphically displayed information not only shows the quantitative distribution of each individual type, but it also provides clues to the source and to the dispersal direction. Pettijohn (1957, pp. 525–528) lucidly summarized the concept of dispersal by saying : " Although the products of weathering may be widely dispersed, there is a tendency for those produced in any one area to move out in a systematic manner and to be spread out over a rather well-defined region or area. Such a region or area, whether large or small, is a dispersal shadow deposited downcurrent from the generating or source area ".

The dispersal vectors presented are proposed as reliable indicators of transport. The direction of each vector was determined by drawing a line along the axis, or axes, of major concentration for every contoured salient, with the vector origin in the region of maximum concentration. The length of the vector is proportionate to the distance each salient extends geographically, and it normally represents the distance from a local source to the zone of diminution by mixing. In some cases, the vector extends slightly beyond the limiting contour of the salient, and this extension is based upon data for samples beyond the contour. In the instances of certain charted trends which suggest zones of transport, but for which no definite directions of diminution are apparent, " headless " lines are drawn. Obviously, critical judgment is an important part of the vector approach to dispersal study.

In the following pages an attempt has been made to point out for each petrographic type those salient trends, or dispersal patterns which are important and most likely to lead to the recognition of sediment sources and zones of effective transport.

(1) *Quartz, straight extinction, clear.* Study of its charted distribution (Text-fig. 9) suggests that there are five areas containing anomalously large amounts of this grain type. First, the area along the western margin of the survey, delimited by the 30% contour, which extends from Station 250 (32%) in the north to Station 260 (47%) in the south. The stations within this area are largely in zones of medium grained sands, and high values at Stations 260 and 269, both above 40%, suggest a source for these quartz grains outside and to the south of the study area. Second, an area west of Towyn defined by Stations 58 and 276, both over 40%, and nearby stations with over 30% clear, straight extinction quartz. Another small area near Towyn, also with values over 30%, is in the vicinity of Stations 30 and 277 and is due south of Towyn. Third, two areas which in all likelihood are contiguous zones of sedimentation, are the area south of Sarn Wallog (Stations 46, 47, 263, 264, 265 and 267), and the area just west of the sarn bounded by Stations 48, 261 and 262. The dispersal pattern of clear, straight extinction quartz in this general region, like that farther west, suggests transport from the south part of Cardigan Bay. Fourth, a combined littoral-estuarine dispersal zone extending from near Station 132, west of Ty-wen, thence northward along the coast, around the spit at Barmouth and up the south side of the Mawddach estuary to the vicinity of Station 140. All the stations within this area, except 41 (37%), have values between 30 and 33%. Fifth, the large U-shaped area which is developed in the extreme northern end of the survey, i.e., in the corner formed by Sarn Badrig and the coast with a mid-bay, south-westerly extension through Stations 101 to 274. This area, both in its shape and in its higher content of clear, straight extinction quartz, suggests that this quartz type is being supplied from beyond the sarn, and in a considerable quantity. While no petrographic data are yet available for sediments north of Sarn Badrig, it appears that a source there is likely, and some detritus is transported over the sarn at shoaling depths. There is no field evidence to suggest that the Afon Ysgethin provides detritus in considerable volume. It is unlikely, then, that this particular grain type could be introduced by such a small stream in an amount sufficient to account for the anomalous concentration in this northern area.

The irregular, elbow-shaped pattern of dispersal is explained as the composite effect of the two sets of tidal currents, each varying in magnitude and direction with the respective tidal period.

(2) *Quartz, slightly undulose extinction, clear.* Although Folk (1961) and Blatt & Christie (1963) have offered opposing arguments on the origin of quartz with undulose

FIG. 9. Distribution of clear quartz grains with straight extinction. Contour interval 10%.

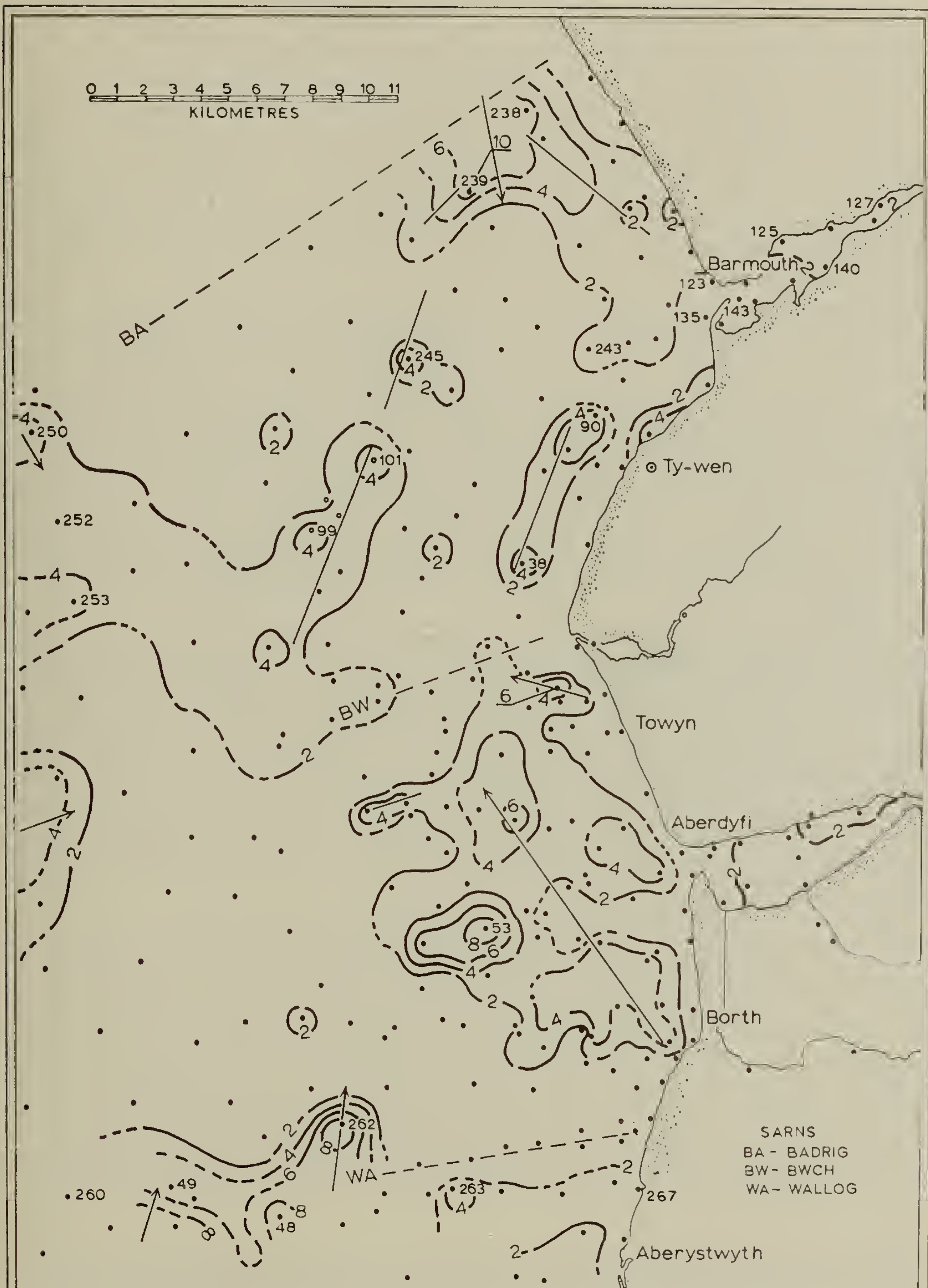

FIG. 10. Distribution of clear quartz grains with strongly undulose extinction. Contour interval 2·0%.

extinction, it is not necessary to establish conclusive evidence supporting either viewpoint in order to characterize such grain types empirically.

This grain type is concentrated in the shallow, inshore sands and its dispersal from the eroding cliffs south of Borth is confirmed by the data for stations in that area. In general, this quartz variety is transported northward and it is unrelated to either river system. The slight enrichment in deposits along the south side of the Dyfi estuary is the result of inward transport from the sea and subsequent deposition in the marsh flat. A small amount of this quartz type may be introduced from beyond Sarn Badrig, probably transported through the trough on the landward end of the sarn.

(3) *Quartz, strongly undulose, clear.* In common with slightly undulose, clear quartz, the strongly undulose variety shows a definite dispersal development in fine sands inshore between Borth and Sarn Bwch (Text-fig. 10). The 2% contour encloses several smaller areas wherein values exceed 4%, and are as high as 8% at one station [53]. Although sample station control does not allow one to bring all 4% contours together, it appears reasonably certain that these smaller, higher percentage areas are contiguous. Another area with high values, which appears to be a zone of transport, is located west of the outer end of Sarn Wallog. Stations 48 (8·1%), 262 (8·1%), 49 (5·4%) and 260 (5·3%) establish the charted concentration, and when combined with Stations 263 to 267 inclusive, suggest an origin south of the survey.

A typical dispersal shadow is developed in the northernmost part of the survey based on data for Stations 238 (7·3%) and 239 (10·0%). In referring to Text-fig. 10, the progressive diminution of strongly undulose, clear quartz in a southerly direction is suggestive of a source north of Sarn Badrig. Inasmuch as Stations 90 (5·0%) and 243 (2·4%) are only 2 km. apart, it is reasonable to assume that the dispersal extension of this quartz type southward to Station 38 (4·9%) is continuous and related. Presumably, the undulose grains dispersed northwesterly from off Aberdyfi, and southeasterly from the northern source (through Stations 245, 101 and 99) provide the coalescing pattern which then extends northwesterly toward Stations 253, 252 and 250.

There is no evidence to suggest that strongly undulose, clear quartz is dispersed from within the Mawddach estuary system. Three selected stations at the mouth of the estuary in the vicinity of Barmouth, numbers 135, 143 and 123, while texturally similar to the other nearby sands, do not exceed 0·9%. Three stations within the upper estuary with values exceeding 2%—Stations 125, 140 and 127—do not negate the preceding observation, in that all three were sampled in marsh sands, sediments which were deposited during periods of highest tides, as determined from field evidence. Several samples from the Dyfi estuary contained strongly undulose, clear quartz in amounts between 2 and 3·5% ; such is thought to have been brought in from Cardigan Bay. None of the river samples in this region contained strongly undulose, clear quartz.

(4) *Quartz, semicomposite extinction, clear.* One of the most informative charts to be prepared during the course of this study is that drawn on the basis of data

for semicomposite extinction, clear quartz (Text-fig. 11). The major dispersal pattern for this particular grain type is such that no basis exists for an alternative interpretation. Reference to the chart shows that semicomposite, clear quartz, in amounts over 1%, is effectively restricted to an area extending northwesterly from the cliffed coast near Borth, and terminating near the seaward end of Sarn Bwch. Its distribution, as delimited by the contour lines drawn for values between 1 and 6%, provides an almost ideal example of the dispersal shadow as defined by Pettijohn (1957). A minor local source of this quartz type is the coastal area of eroding cliffs between Borth and Sarn Wallog. No semi-composite, clear quartz was found in stream bed deposits of the Dyfi or the Mawddach. In summary, semicomposite, clear quartz is restricted chiefly to that part of the study area south of Sarn Bwch, and the main source appears to be, or be near, the eroding sections between Aberystwyth and Sarn Wallog.

(5) *Quartz, composite, clear.* Unlike the preceding variety, composite, clear quartz is primarily dispersed in the northern part of the study area (Text-fig. 12). There is, also, a partial development along the western margin of the area between Stations 259 and 118, suggesting dispersal from beyond the westward limit of this study. The contour which delimits this local increase is based on four stations with values over 2%, and one station with a value of 4·5% (257).

Dispersal in the far northern part of the area is confined to three almost parallel extensions, which have a common zone along the coast between Barmouth and Mochras. They may not be related, however, to a common source and, thus, are considered separately. The first and most pronounced dispersal trend is that aligned from Station 79 near the end of Sarn Bwch northward through Stations 98, 101, 245, 219 and 236. This elongate zone contains two stations, 98 and 101, with values between 4 and 6%. It is suggested that greater amounts in the northern part of this dispersal lineament have been masked or diluted by the influx of other varieties being brought in from north of Sarn Badrig. The second dispersal zone extends from the cliffed coast west of Ty-wen northward and parallel to the coast to the Mawddach estuary mouth. Littoral sands along the coast in this area are somewhat higher (by about 2%) than the deeper water deposits seaward from them. This observation together with the recognized northward drift of inshore sands is suggestive of a source in the vicinity of Stations 132 and 133. Glacial deposits are being eroded nearby, and they probably serve as the local source for composite, clear quartz found in these nearshore and littoral sands. The third dispersal trend is that based on three stations, 272, 222, and 221, parallel and immediately adjacent to Sarn Badrig. These stations appear to lie in the zone of fine sand transport located close to the sarn. The dispersal patterns for this zone and the mid-bay zone appear to be related to a common source of composite, clear quartz somewhere north of Sarn Badrig and beyond Mochras. Certain samples within the Mawddach estuary (142, 141, and 127) with amounts between 2 and 3·7% do not, in themselves, suggest that the Mawddach river system is providing composite, clear quartz.

Briefly, composite, clear quartz is primarily dispersed in the northern portion of the study area, and it appears to be derived from the glacial deposits near Ty-wen

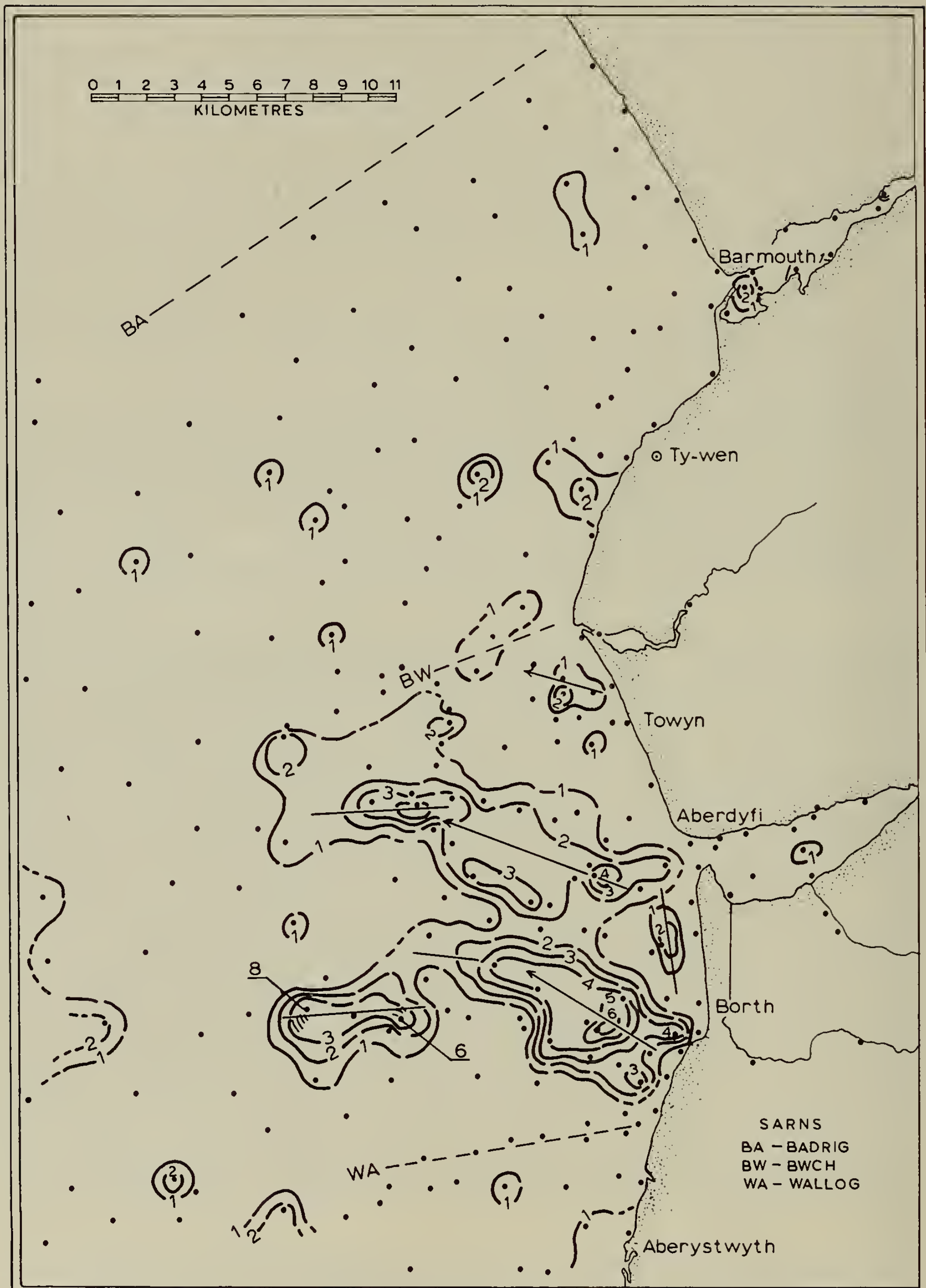

FIG. 11. Distribution of clear quartz grains with semi-composite extinction. Contour interval 1·0%.

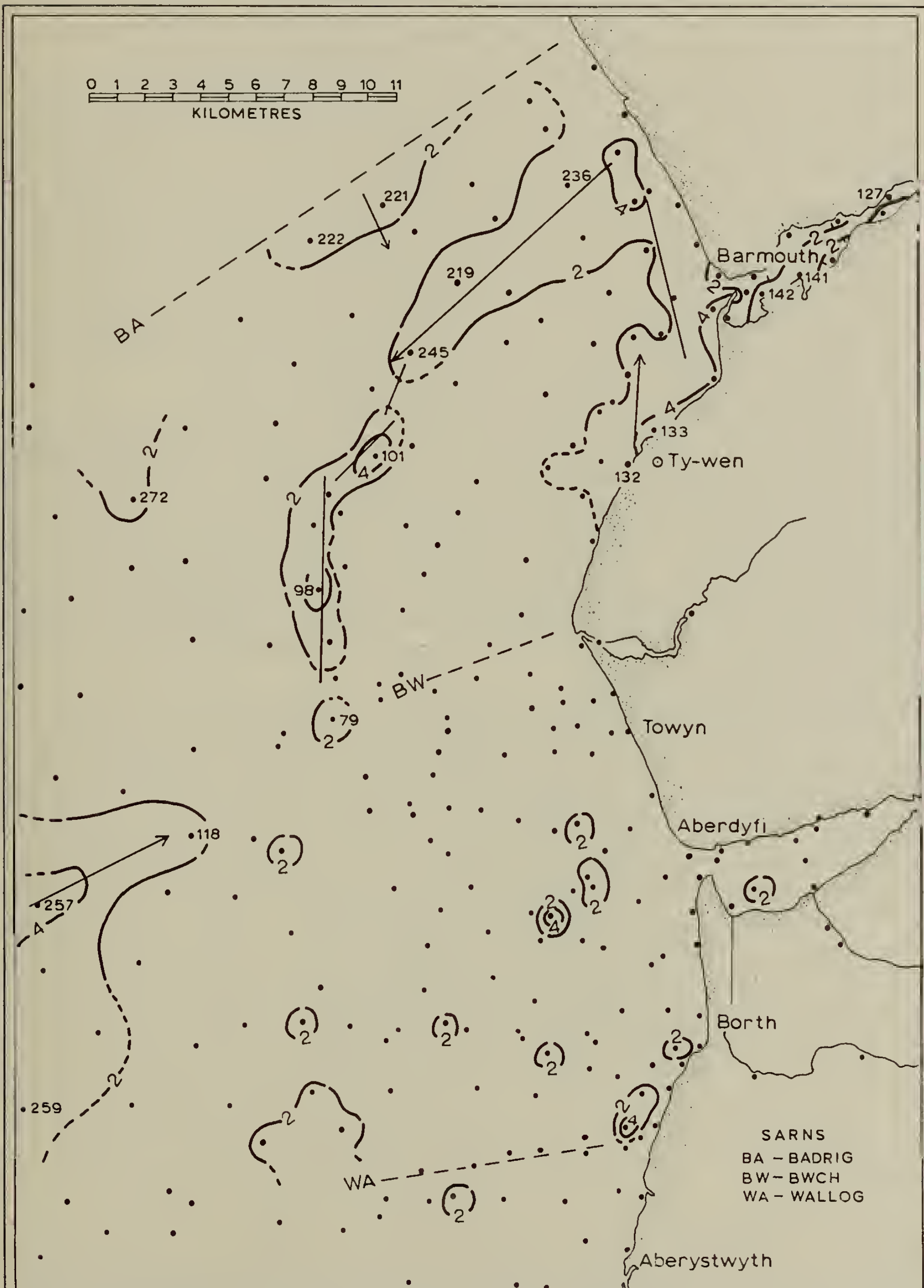

FIG. 12. Distribution of clear quartz grains with composite extinction. Contour interval 2·0%.

and an unknown source beyond Sarn Badrig. Although small quantities were found in Mawddach estuary sands, their presence is not considered important.

(6) *Quartz, composite metamorphic, clear.* The dispersal pattern of this quartz type (Text-fig. 13) presents a readily understood distribution. On the basis of the reported data, it is dispersed from the vicinity of the cliffs south of Borth, and is distributed in a general northwesterly direction. It is unlikely that Stations 31 and 32 with between 2·0 and 3·2% composite metamorphic, clear quartz constitute a separate dispersal zone, for while sample coverage is not dense enough to permit detailed contouring, this area is most likely connected with that to the south. Isolated stations such as those found in the northern part of the survey (85, 92, 123, etc.) do not appear to be part of any plan. In all, composite metamorphic, clear quartz is being dispersed only in the offshore sands west of Borth, and probably owes its origin to erosion of the coastal cliffs of Aberystwyth grits.

(7) *Quartz, straight extinction, vacuole inclusions.* This is one of the most common quartz types present in the Cardigan Bay sands, and it is difficult to establish definite dispersal trends and even more difficult to conclude where it may originate. Of course, the fact that any specific grain type is ubiquitous may well suggest it is part of the reworked detritus, distributed earlier by the transgressive sea. In some respects, this grain type may be thought of as one which forms a part of the detrital " background ", or pre-existing clastic matrix. Nevertheless, there is some suggestion based on data for stations within the Mawddach estuary, that a source upstream for this quartz type, at least in very small quantities, is possible. The data are not, however, conclusive.

(8) *Quartz, slightly undulose, vacuole inclusions.* This grain type occurs in amounts about twice that for the previously reported clear variety. The vacuole type, however, presents a more meaningful distribution in that its dispersal is within an elongate, contiguous zone paralleling, but offshore from, the coast. Inasmuch as slightly undulose, vacuole inclusion quartz is relatively common in these nearshore sands, it was charted for quantities above 10% in order to delineate its dispersal (not figured) in the northern part of Cardigan Bay. One source appears to be the eroding cliff section just north of Sarn Wallog. Several stations in this area, notably 150 (15·5%) 151 (16·6%) and 17A (12·7%), provide substantial evidence for concluding that a dispersal centre exists there. Another source of this grain type is the eroding glacial debris in the vicinity of Towyn, for immediately offshore Stations 66 (17·0%), 67 (13·7%), 65 (15·1%) and 32 (12·4%) all possess greater amounts of this grain variety than do stations surrounding them. In fact, these stations provide a sound basis for contouring the lobed distribution outward and southward from the Towyn area. In summary, a major dispersal originates in the cliffed coastal area south of Borth, with a subsidiary source in the vicinity of Towyn. There is no dispersal area of significance in the northern part of the survey.

(9) *Quartz, strongly undulose, vacuole inclusions.* With a distribution pattern somewhat resembling the previous variety, the strongly undulose, vacuole inclusion quartz is distributed in a linear irregularly shaped band extending from Borth northward along the coast to the inshore end of Sarn Badrig. Inspection of the

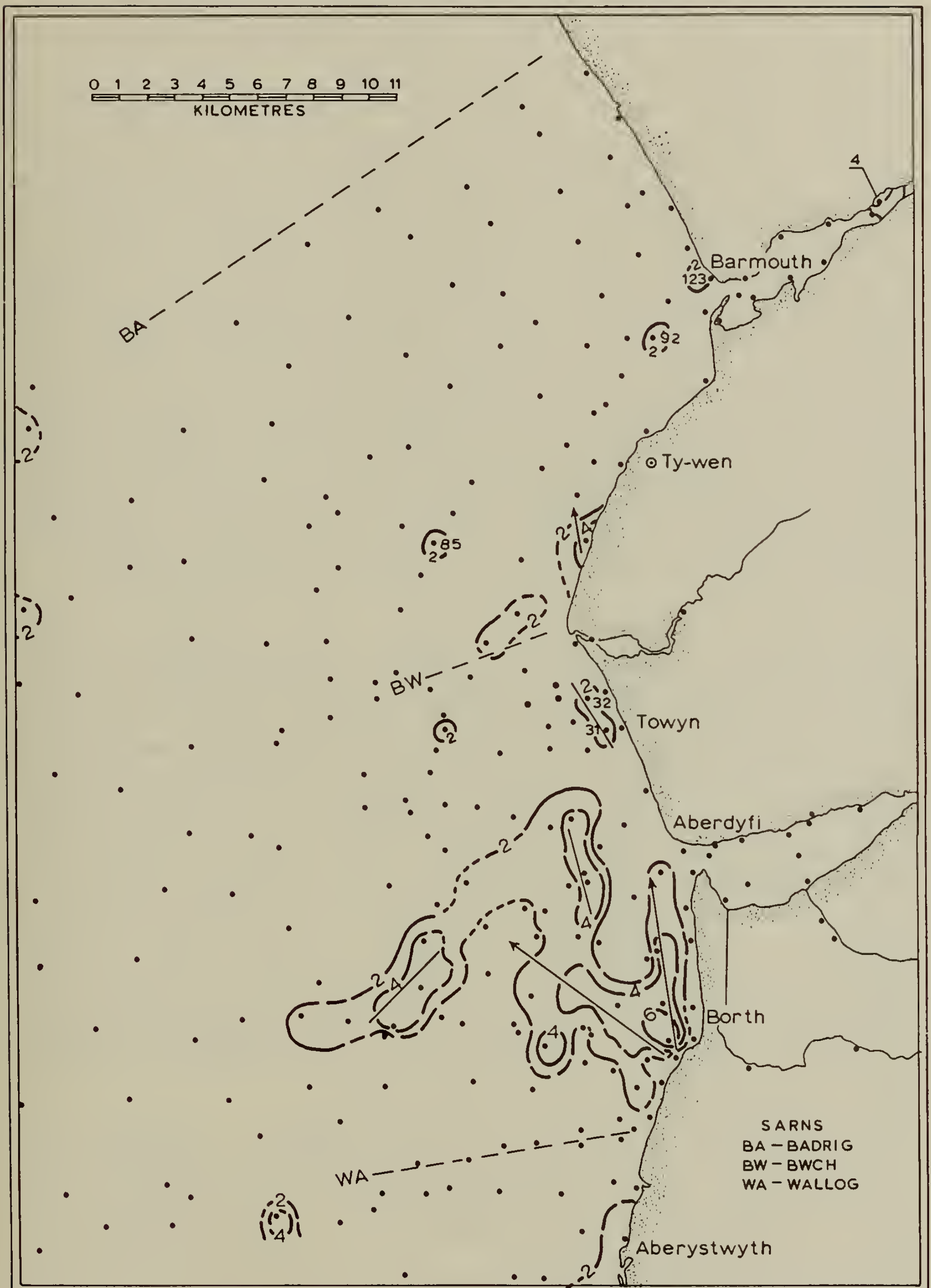

FIG. 13. Distribution of clear quartz grains with composite metamorphic extinction. Contour interval 2·0%.

dispersal plan (Text-fig. 14) shows that significant amounts are also found in the far western part of the present survey. Inasmuch as the highest values reported are for those stations west of the Borth beach, Stations 21, 54, 51 and 60, one may conclude that the southern part of the survey is a centre for local dispersal of this grain type. Here again it seems evident that the cliffed coast near Borth serves as a centre from which much of this quartz variety is dispersed in northern Cardigan Bay. However, southward directed tidal currents entering the area from Tremadoc Bay, over the landward end of Sarn Badrig, may transport additional amounts of this grain-type into the area. This is based upon data for Stations 238 (8·8%), 237 (7·4%), 239 (7·4%), 241 (7·6%), 236 (6·8%) and 244 (8·2%). As the geographic arrangement of these stations is such to provide a dispersal shadow with the data maxima farther north, it is concluded that strongly undulose, vacuole quartz is introduced from Tremadoc Bay. Neither the Afon Mawddach nor the Afon Dyfi transport this type of quartz to Cardigan Bay. Likewise, none of the smaller streams are active carriers of this quartz, nor is it found in quantities over 5% in the littoral, or beach sands with the exception of Stations 173 and 133. In regard to this observation, i.e., the lack of appreciable amounts of undulose quartz in the littoral deposits, it is indeed possible that some strained varieties of quartz are susceptible to erosional fracturing under high energy conditions prevailing in the surface zone, and even offshore where large waves dissipate their energy against the bottom.

(10) *Quartz, semi-composite, vacuole inclusions.* Relatively large amounts of semi-composite, vacuole quartz reported for Stations 9 (9·2%), 17 (8·1%), 18 (7·7%), 6 (8·8%) and 180 (7·4%) suggest that this variety is derived from a source in the coastal area just south of Borth (Text-fig. 15). Indeed, even those littoral samples largely composed of lithic grains (144, 148 and 149) contain a higher amount of this quartz than might otherwise be expected, due, of course, to their proximity to the local source. If one follows the general dispersal trend enclosed by the 4% contour, a noticeable correlation of distribution with the northward axis of the tidal current system is seen. Thus, by beginning near the cliffs and tracing the 4% contour one may draw a reasonable path for transport northward to its intercept by Sarn Bwch. At Sarn Bwch the dispersal turns westward and continues to the end of the sarn. As outlined in previous discussions on tidal currents and textural distribution, the present dispersal plan likewise follows a similar pattern by extending a dispersal halo north of Sarn Bwch, and terminating (based on the 2% contour) in the vicinity of Station 88. There is, of course, a westward dispersal of this quartz type which is somewhat less sharply defined but still obvious from the evidence of Stations 22, 76, 116 and 201, all with values above 4%.

Fine sand is being transported into the estuaries from the bay. The present distribution chart (Text-fig. 15) supports this significant observation. Reference to the chart shows that a delimiting 2% contour irregularly crosses the Dyfi estuary, seaward of which values in excess of 6% are contoured. On the other hand, there is, east of this contour, a noticeable decrease for the several stations from 1·8% at Station 169 to nil further to the east

An apparent, but minor, dispersal suggesting an origin beyond Sarn Badrig and

FIG. 14. Distribution of quartz grains with strongly undulose extinction and vacuole inclusions. Contour interval 5·0%.

showing transport over the far outer edge of the sarn, is developed on an axis through Stations 216 (8·9%), 231 (5·7%) and 224 (3·5%). Were it not for the progressive increase of this quartz variety toward the end of the sarn, one might offer the alternative of connecting Stations 87 and 224 in an area of coarse clastic deposits which, texturally at least, appear to be related.

(11) *Quartz, composite, vacuole inclusions.* Although this quartz variety appears to be dispersed away from the glacial exposures near Ty-wen in minor amounts, its main zone of enrichment is along the shore in beach deposits. Some local accumulation occurs on the north side of the Dyfi estuary, but seems unimportant. The concentration of this quartz variety in the beach and nearshore zone suggests that it is primarily transported by drift currents. Indeed, it may be simply a transient grain variety with a source elsewhere in the bay. Its distribution offshore cannot be rigidly defined or interpreted.

(12) *Quartz, composite metamorphic, vacuole inclusions.* For the majority of the samples from northern Cardigan Bay, composite metamorphic, vacuole inclusions quartz was found to be present in amounts less than 2% ; in about half of them this variety accounted for less than 1 % of the grains. In most of the offshore area it is randomly distributed, and the data do not suggest a definite dispersal pattern except in the western margin of the survey. This exception, a lobe-shaped zone in the west-central portion of the survey, is recognized on the basis of data for Stations 118 (2·2%), 195 (2·7%), 196 (5·1%), 247 (3·0%), 271 (2·7%), 272 (4·2%), 229 (2·4%) and 224 (4·1%). Inasmuch as these stations are near the margin of our present survey and as no data are available for the deposits farther seaward, the present dispersal plan suggesting a source, or zone of transport, beyond the seaward end of Sarn Badrig must be considered a provisional one.

Two local areas of concentration are the littoral zone paralleling the cliffs south of Borth and the littoral zone between Aberdyfi and Sarn Bwch. There is no evidence to suggest that this quartz type is transported to the sea through either the Dyfi estuary or the Mawddach estuary.

(13) *Quartz, all extinction types, microlite inclusions.* Because quartz grains containing microlites were largely restricted to the straight extinction class, the author has grouped them in a single category for this study. A dispersal plan which is both easily determined and straightforwardly interpreted is evident (Text-fig. 16). Furthermore, the contoured plan is developed with the characteristic dispersal shadow form (Pettijohn, 1957) with those stations having the largest percentages being restricted to a narrow zone northwest of the cliffs near Borth. The apparent axis of dispersal is northwest from the cliffs to the end of Sarn Bwch where a secondary zone extends westward. From the end of Sarn Bwch, or near that general vicinity, a dispersal trend extends northeastward to within the vicinity of Station 217. Some microlite-bearing quartz is dispersed northward from near Towyn. For the latter dispersal, which joins the main northward transport zone, a source near Towyn, probably the glacial debris exposed there, is suggested. This type of quartz is not being delivered to the bay through the Mawddach and Dyfi estuaries, nor is it being introduced from beyond Mochras point in the north.

FIG. 15. Distribution of quartz grains with semi-composite extinction and vacuole inclusions. Contour interval 2·0%.

(14) *Quartz, all extinction types, rutile inclusions.* For most of the estuary and bay deposits, quartz grains with rutile inclusions (" fine needles ") occur in small amounts (Text-fig. 17). Indeed, only eleven stations have values exceeding 2 % and for only two stations do values exceed 3 %. Within the southern half of the survey, a dispersal of this quartz variety extends irregularly northward from the outer area of Sarn Wallog. While this might be the result of submarine erosion of westward extending sarn deposits and their subsequent transport northward, a more likely explanation may be a distant source south of Sarn Wallog. The few data from this southern area do not permit a firm conclusion. In the northern part of the survey adjacent to the outer Sarn Badrig region, a second centre for dispersal of rutile-bearing quartz is developed. There are no data which suggest that this quartz variety is being delivered through either of the two major estuaries. In short, its chief source area is apparently beyond the limits of this survey.

(15) *Quartz, chloritic inclusions, all extinction types.* Chlorite-bearing quartz is dispersed from two source sites. The first, and more important, are the exposures of glacial debris along the coast south of Barmouth. The second is indicated by a weakly developed pattern along the Borth beach. It is probable that the chloritic quartz from these two areas is of different origin. Some patchy development of this quartz variety occurs offshore, but no obvious pattern can be discerned.

(16) *Quartz, secondary overgrowth.* In spite of the paucity of grains with overgrowths (0·0 to 2·7 %, av. 0·5 %), it is possible to establish two dispersal plans (not figured) for the bay sands. The first is an elongate zone extending northward from Sarn Wallog in mid-bay and its northward extension beyond Sarn Bwch, and the second is the littoral area between Sarn Bwch and Eglwys Llanaber, also including the lower Mawddach estuary. In the latter instance, it appears that grains with secondary quartz overgrowths are transported into the estuary from littoral deposits between Ty-wen and Barmouth. With the exception of littoral sands north of Sarn Bwch which may come from the erosion of glacial debris along the coast there (Pl. 2, fig. 2), the major dispersal of this grain class appears to originate in the southern part of the study area, perhaps associated with Sarn Wallog, but more likely from a distant source beyond the southern limit of this survey.

Arenite fragments. The distribution of arenite fragments (Text-fig. 18) is based solely on the sampled and analysed sand deposits, and on certain coarser clastics which are not part of the sarn accumulations. The sarns are composed of gravels and boulders. This discussion relates to the *relatively* more mobile sediment cover of the Cardigan Bay bottom. The same qualification applies to comments on certain other distributions, namely slate fragments and crystalline rock fragments.

The most noticeable pattern and, perhaps, the most significant one, is that which extends northward from the cliffs at Borth and is eventually directed seaward in the vicinity of the mouth of the Dyfi estuary. This dispersal pattern suggests an origin for much of the arenite debris in the vicinity of the cliffs just south of Borth, an observation which, incidentally, is supported by field study (Pl. 2, fig. 1). Stations along the littoral zone at the base of the cliffs between Aberystwyth and Borth possess not less than 21·5 % arenite fragments (Station 267), and at one station (180) their content reaches 46%. Those stations at the base of the cliffs between Sarn Wallog and Borth owe their enrichment of rock fragments to erosion of the immediate cliffs (Pl. 2, fig. 1). A progressive diminution of arenite fragments is noted when one considers the data for Stations 25 (14·1%), 17 (9·4%), 18 (8·6%), 205 (6·2% and 11 (4·3%). These stations are all in line seaward of Borth. A consistent amount (between 10 and 11%) is reported for those samples along the beach front between Borth (Station 150) and the outer spit (Station 153). The distribution of arenite fragments in the lower Dyfi estuary and in the vicinity of its opening to the sea at Aberdyfi suggests their dispersal *into* the estuary from the bay. Station 20, some 11 km. west of Borth, with 37·2% arenite rock fragments, is considered an anomalous station, and its higher content is attributed to textural influence (ϕ *Mz*, —1·2) ; the same is true for Station 4 (ϕ *Mz*, —1·0). In most of the sands from both the southern and northern parts of this survey, the arenite fragments are present in amounts varying between 4 and 9%.

A second source is the glacial debris in the vicinity of Towyn, which shows its influence westward for some 3½ km. Station 171, immediately in front of the eroding shore at Towyn, contains 24·5% arenite fragments, and Station 65, about 1½ miles west of it, contains 13·3% ; thus, the lithic content diminishes rather rapidly with increasing distance seaward. The control of this diminution may be either the limited amount of material available, or it may be that lithic fragments are broken into constituent sand grains as they pass through the high energy surf zone.

In the northern part higher values for Stations 272, 216, 222, 221 and 215, all between 10 and 15%, suggest that the arenite grains in this area are derived from Sarn Badrig. Likewise, random Stations 224, 226, 196, 182 and 183, with values over 10%, may be related to sarn erosion or to textural control, and need not necessarily be part of a dispersal scheme. It should be noted that the significantly higher arenite content of the several stream samples correlates with the larger grain sizes. There is no evidence suggesting that arenite grains are being spread over the estuaries by their associated streams.

Slate fragments. In the southern half of this survey two dispersal patterns are of major importance in understanding the distribution of these grains, as well as several of the chemical elements. The first of these patterns is the dispersal zone from the cliffed area south of Borth. This area is delimited by 5% values, although within it sands with slate fragments in amounts less than 5% are known. The stations in the latter area (51, 52, 4, 68, 1 and 2) show a wide spread of values below 5%. Station 1 with 0·8% and Station 2 with 2·4% suggest local masking by other grain types, and Station 4 with no slate fragments may be an expression of textural control. Station 20, approximately 10 km. west of Borth, is an anomalous station within the area, since it contains 16·2% slate fragments, and may represent an extension of the charted higher fragment content deposits westward some 5 km. In general, however, the littoral deposits between Aberystwyth and Borth with values exceeding 20% in places suggest the nearby cliffs as the immediate source.

Farther offshore, a pronounced tongue-shaped dispersal pattern extends north-

FIG. 16. Distribution of quartz grains, all extinction types, with microlite inclusions. Contour interval 2·0%.

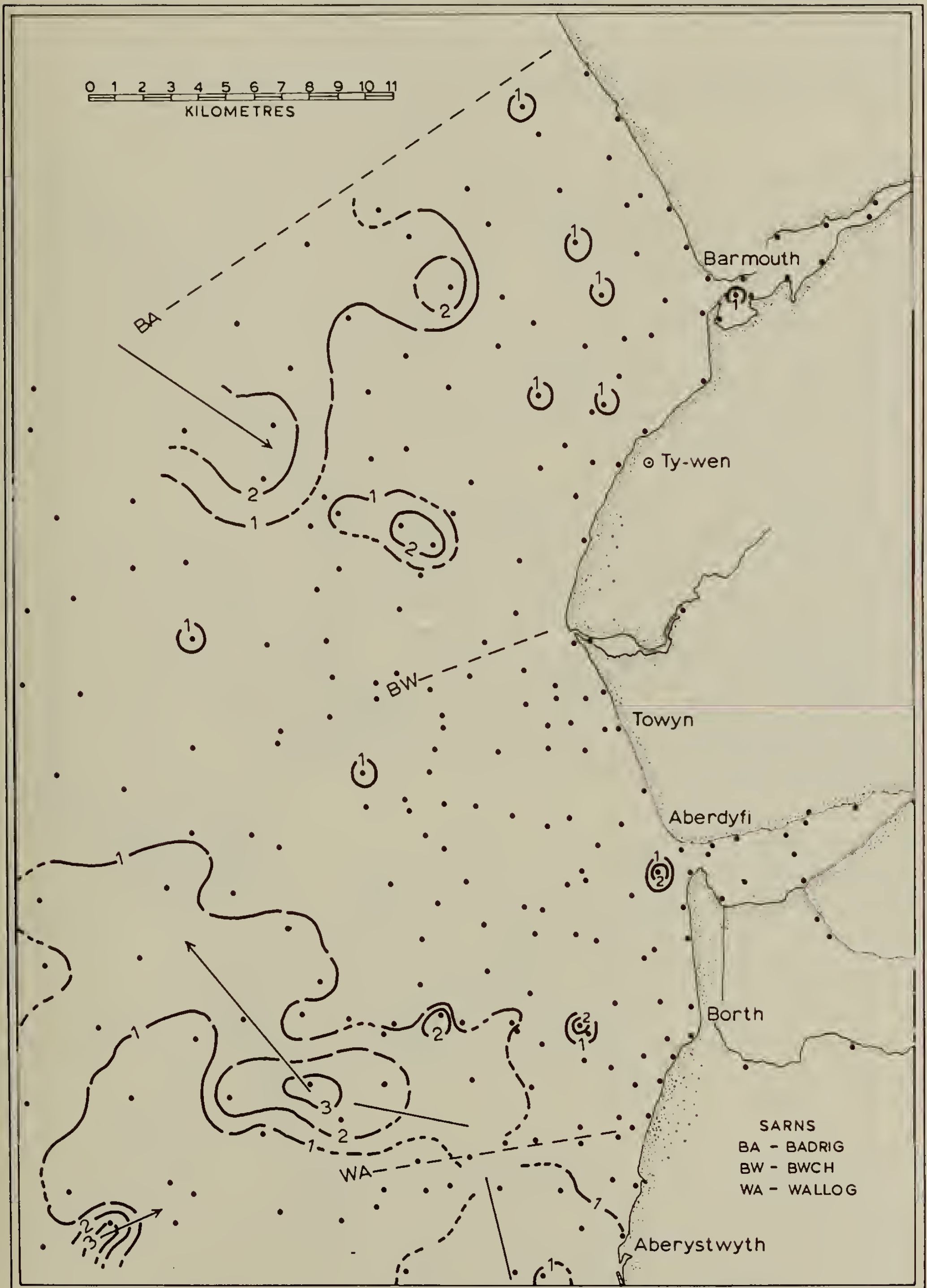

FIG. 17. Distribution of quartz grains, all extinction types, with rutile inclusions. Contour interval 1·0%.

FIG. 18. Distribution of lithic arenite fragments. Contour interval 10%.

westward from the other part of Sarn Wallog. Within this zone, which is delimited by 5 % values, there are several stations with values above 10 %, namely 109 (12·0 %), 201 (14·0 %) and 191 (14·9 %). These deposits are poorly sorted, and it is suggested that they have been derived by erosion of the outer parts of Sarn Wallog and transported northwestward by bottom currents.

In the northern part, a linear band of slate-containing sediments commences in the vicinity of a coastal source near Tal-y-garreg, and extends in a northwesterly direction until it reaches Sarn Badrig. Additional slate fragments in this northern zone may originate south of Sarn Bwch near Towyn and, perhaps, be joined by others eroded from the cliffs north of Sarn Bwch. There are no samples with significantly higher values, i.e., at least 10 %, in the northern region which would indicate that slate fragments are being introduced from beyond Sarn Badrig. However, stations around the seaward end of Sarn Badrig (all over 5 %) may be influenced by lithic grains eroded from the sarn itself. From the end of Sarn Bwch westward, a zone of coarse sediments with slate fragments in amounts above 5 % suggests that these are derived from Sarn Bwch. Station 196 with 22·0 % is anomalously high, and it may reflect textural control (ϕ *Mz*, − 1·2).

Locally within the Mawddach estuary, some deposits exceed 5 % slate fragments, but these are restricted to areas of known temporary entrapment and do not suggest that slate fragments are being contributed to the offshore sands by any source related to that estuary. This observation is further supported by the absence of a dispersal shadow seaward of the estuary mouth. While the Dyfi does not appear to be a transport zone carrying slate particles to the bay, a minor enrichment zone is apparent in the upper estuary (163 with 25·9 %, 169 with 11·5 %, 158 with 10·0 %) Slightly higher values at Stations 146 and 167 are indications of the coarser grained deposits there. In summary, the two important dispersal centres are the cliffs at Borth, and the seaward end of Sarn Wallog. Minor amounts of slate are deposited in the upper Dyfi estuary.

Crystalline rock fragments. All crystalline rock fragments, regardless of their type or clan, are grouped into a single classification in Text-fig. 19. Three dispersal zones are recognized. First, a zone delimited by a 2 % contour, which extends irregularly westward just north of Sarn Wallog. Crystalline rock grains in this area are of several varieties. Second, a zone in the northwestern part of the survey wherein the crystalline rock fragments are also of several varieties. This area appears to be related to a dispersal centre beyond the limits of the survey. Third, inshore, in the northern part of the area is a dispersal zone extending from just north of Sarn Bwch to the vicinity of Eglwys Llanaber. A typical dispersal shadow is established adjacent to the coast between Sarn Bwch and the entrance to the Mawddach estuary.

While the upper Mawddach estuary contains crystalline rock fragments in amounts exceeding 3 %, indeed as much as 28 % in the coarse-grained stream deposits at Dolgellau, there is no suggestion that the Mawddach delivers any significant amount of crystalline rock fragments to the bay. In fact, the middle Mawddach estuary area is noticeably deficient in crystalline fragments, an observation which is sup-

FIG. 19. Distribution of crystalline rock fragments (all varieties). Contour interval 2·0%.

ported by the data for Stations 129 (0·6%), 140 (0·9%), 141 (0·6%) and 125 (1·8%). If crystalline fragments in significant amounts are presently transported through the Mawddach estuary, they would have been observed in these samples. Certain of the crystalline fragments found in offshore sands west of Ty-wen resemble, in thin-section, crystalline rock types occurring in the Cader Idris area nearby.

Chert. It is apparent from the chart (Text-fig. 20) that these grains are being dispersed westward from the vicinity of Borth, and that their source is the Aberystwyth grit beds exposed in the cliffs nearby. Since detrital chert fragments are normally derived from eroded limestone, this suggestion of local origin, i.e., the Aberystwyth grits, implies a complex relationship of multi-cycled grains, first deposited in the Aberystwyth grits and now being eroded and deposited in the bay. A small development offshore from Towyn suggests that chert fragments in the deposits there are derived from the exposed glacial sediments along the shore. There is no evidence that chert grains are transported to this area by the rivers, or by currents from beyond Sarn Badrig.

(c) *Comparative petrography*

Use of photomicrographs taken of thin sections for certain of the Cardigan Bay and associated stream samples provides a direct, visual method for sediment comparisons. While photomicrographs taken at low magnifications are not suitable for classifying specific quartz varieties, they are, on the other hand, useful for illustrating major compositional variations between selected samples.

One of the initial questions in this study involved the determination of detrital types which might be carried by the rivers and deposited in the estuaries, or in the bay itself. Certainly the preponderance of fine grained quartz sand in the Dyfi, as well as the Mawddach estuary, should be related to the transport of similar quartz sand in the adjacent rivers if the rivers supply the sand. However, thin-sections of river sediments upstream from the Dyfi estuary are all but devoid of fine and medium size quartz grains. Even such samples as the one at Station 160 in the Dyfi, a sample containing sand sized lithic material, is noticeably lacking in quartz grains as discrete clastics. To illustrate the major change between sediments in the Dyfi river and those in the upper Dyfi estuary, consideration will be given to four typical photomicrographs. In Pl. 3, fig. 1, a photomicrograph of the river sediments at Station 162 near Machynlleth, there is a predominance of lithic fragments. This photomicrograph is, indeed, typical of most of the mobile sediments in the Dyfi river in the vicinity of Machynlleth. While rare fragments of arenites have been seen in the course of field study, most of the clastics are fragments of slate and shale. If mechanical breakdown of lithic fragments being rolled or otherwise transported by the river was the source of sand size quartz, i.e., by mechanical disaggregation, then it would be expected that parent lithic fragments should contain abundant sand size quartz grains. Pl. 3, fig. 1 shows that this is clearly not the case. In Pl. 3, fig. 2, a photomicrograph of a thin section of sample 161 some 3 km. downstream, the lithic fragments are slightly smaller in size but are the same in composition. It will be noticed that the only real change is in the texture

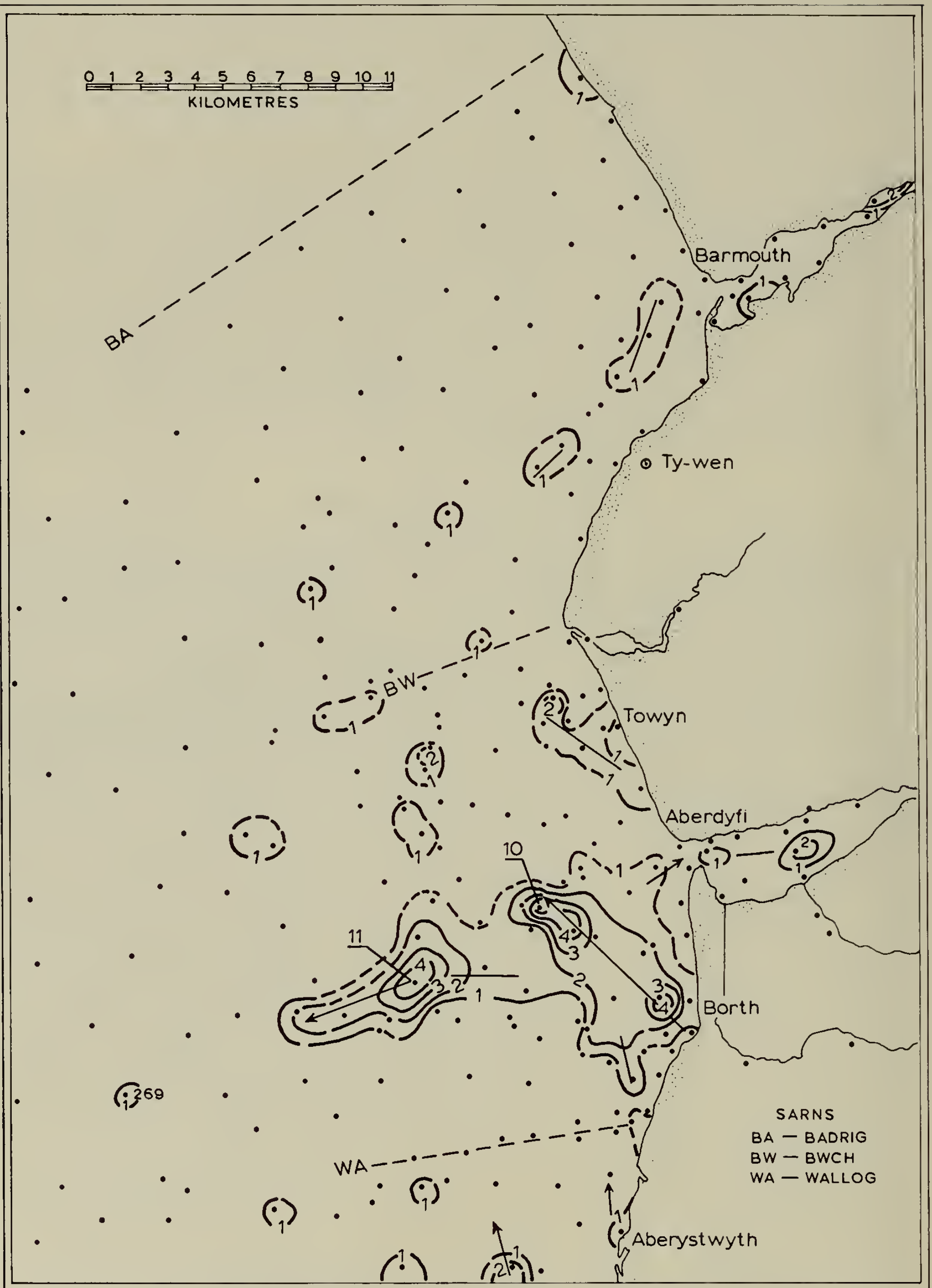

FIG. 20. Distribution of chert fragments. Contour interval 1·0%.

of the sediments. The lithic composition remains that of slate. However, Pl. 4, fig. 1, for Station 159 in the lower Dyfi valley or upper Dyfi estuary, shows a pronounced change in the aggregate composition of the sediment. This represents a downstream transport direction of about three more kilometres. At this station there is a mixture of lithic fragments similar to those observed at upstream stations and fine quartz sand. At Station 159, the texture is such that the sediment sample is a bimodal one, i.e., large lithic fragments and small quartz grains. Station 159, incidentally, is within the transition environment of " upper estuary/lower river " sedimentation. Farther downstream (Pl. 4, fig. 2, St. 163), the entire textural suite is of sand size and is obviously quartzose in composition. It may be concluded from these four petrographic examples that the fine grained quartzose sand is restricted in its deposition, and does not extend beyond the influence of the highest tides. Consequently, it would seem that while lithic material, normally slate, is being gradually moved downstream, there is no suggestion that quartz sand, such as is found in the estuary, is being moved likewise. Any phyllosilicate grains which might be eroded from larger lithic fragments during the course of stream transport are probably flushed from the estuary, or in some cases entrapped within the marsh (grass stabilized) deposits along the south side of the Dyfi estuary. These conclusions are supported by X-ray diffraction data. At Stations 162, 161, 159 and 163 the concentrations of phyllosilicates are respectively 57, 57, 33 and 14%. This decrease of total phyllosilicates downstream is in agreement with petrographic observations.

Another example illustrating the use of comparative petrography is the characterization of sediments near the cliffs at Borth, and their comparison with deposits further offshore. Pl. 5, figs. 1, 2, photomicrographs of samples from Stations 148 and 144 from the littoral zone at the base of the cliffs south of Borth, show an entirely different grain type assemblage from the Dyfi system. Here the lithic fragments are predominantely arenites and are mixed with quartz grains. In Pl. 6, fig. 1 (St. 150), a sample from the littoral zone at the end of the cliff section associated with the beach environment at Borth, it may be seen that the amount of lithic fragments is somewhat decreased, but with a concomitant increase in quartz grains. The deposit is also one of finer size than the littoral deposits at the base of the cliffs to the south of it. Such a relationship suggests that within the few kilometres of northward longshore drift transport, there is a diminution of lithic material, and this may be explained by the mechanical breakdown of the softer rock fragments into their constituent grains. If we compare, then, these sediments near the cliffs with some deposited farther offshore (Pl. 6, fig. 2), it is readily apparent that the bay sands seaward are relatively richer in quartz grains than are the littoral deposits adjacent to the cliffs. The photomicrograph of a sample from Station 7 (Pl. 6, fig. 2) is a typical example of the fine grained sand flooring much of northern Cardigan Bay.

In summary, gross petrographic comparisons agree with the findings based on single grain studies and suggest that fine quartz is not being delivered to the estuaries by the adjacent rivers, but that it is being contributed to the bay and, in turn, the estuary sediments by active erosion of beds exposed along the shore.

VI. X-RAY MINERALOGY

Although X-ray diffraction analyses of marine sediments, using the powder method, were made as early as the late 1920's (Correns, 1935), it was not until after World War II and the advent of modern diffraction apparatus for making rapid reproducible analyses that sedimentologists began reporting the dominant mineral composition of marine clastics (Grim, 1953). Many X-ray studies of the past few years have been concerned only with differentiating the clay types. However, gross composition data for quartz, feldspars and phyllosilicates are equally valuable for classifying and comparing Recent sediments with other marine deposits, and for providing a reference for chemical and petrographic data. There are, however, several limitations inherent in the X-ray powder method : (1) non-crystalline components are not recorded—volcanic glass, for example, would be overlooked if diffraction analysis were used without recourse to thin section study; (2) gross analysis does not provide quantitative data for minerals present in quantities below about 1 % ; and (3) the method cannot differentiate the textural states of the several components.

(a) *Distribution of minerals*

Muscovite. Mica occurring in the Cardigan Bay deposits is in the form of well crystallized dioctahedral muscovite and is the only one of the 10Å minerals present. With the exception of some very small quantities present as clay-size clastics in estuarine marsh deposits (less than 1 %), the mineral occurs as a constituent of lithic grains, chiefly slate and arenite fragments.

From a study of the data, it is seen that the major fine sand area offshore contains less than 5 % muscovite. The average, in fact, is close to 3 % both for the fine sand area north of Sarn Bwch, and for the fine sand area off the Borth/Towyn coast. Fine sands along the south side of the Dyfi estuary, particularly in the marsh environment, average about 6 % 10 Å mica, which, from petrographic evidence, is contained in very small lithic fragments, normally the smallest sizes of slate fragments readily discernible. Station 146 with 5 % mica is a " coarse sand " (0·3 ϕ *Mz*), and Station 167 (13 %) is a " very coarse sand " (—0·7 ϕ *Mz*) ; in both deposits the higher proportion of mica is due to the larger percentage of coarse lithic fragments present. The Afon Dyfi channel deposits (Text-fig. 2) just upstream from the head of the estuary (Stations 159, 160, 161 & 162) are sands, excepting Station 162 (near the town of Machynlleth), which is gravel (—2·3 ϕ *Mz*). Samples from these stations are reported to have 12, 17, 22 and 23 % mica content respectively, all attributed to lithic fragments.

Stations 159 and 163 in the transition area of the uppermost estuary and lowermost stream influences are interesting and deserve special attention. Station 163, an uppermost estuary deposit, is a fine sand (2·9 ϕ *Mz*) ; it texturally resembles the other " typical " estuary fine sands and possesses a 10Å mica content of 5 %. Yet, Station 159, a very fine sand (3·0 ϕ *Mz*), comparable in grain size to Station 163 and located about 1 km. farther up the channel, has a mica content of 12 %, a pronounced difference. In the same general area, Stations 164 and 164A, very coarse sands (—0·7 and —0·8 ϕ *Mz*, respectively) have 25 and 24% mica content each. Thus, a significant change in mica content occurs between the uppermost " typical " fine sands of the estuary and the deposits of the lower Afon Dyfi and its smaller tributaries. Fine sand in the lower river and fine sand in the upper estuary are texturally similar, yet there is a three-fold decrease of mica in the estuary deposit. In fact, most fine-grained sands in the main tidal channels on the north side of the Dyfi estuary are depleted in mica, the average content being only 2%.

The littoral deposits extending southward along the cliffs near Borth all have mica exceeding 10%, except a beach deposit containing only 6% mica. There is, however, much less mica in the more seaward deposits. These fine sands immediately offshore average only about 3%. As mentioned previously for texture, a sharp boundary exists between the immediate nearshore coarse-grained deposits and the offshore fine sands.

In the Mawddach estuary, the fine and very fine sands constitute, areally at least, the major portion of the deposits encountered there, and contain between 2 and 6% mica. Silt deposits in shallow, protected, partly marsh areas have slightly higher mica contents (11% and 7%). Beyond the mouth of the Mawddach estuary (Text-fig. 2), just off Barmouth, inshore Stations 92, 93, 94, 122 and 135, all fine sands, have about 2% mica content.

The coarse and medium sand deposits, offshore and northwest of Towyn, were found to contain more mica than the fine sands surrounding them ; similarly, the tongue of poorly sorted coarse and very coarse sands extending northwestward from the outer Sarn Wallog area has higher mica percentages than the surrounding fine sands, an increase due to lithic fragments.

In summary, X-ray diffraction data reported for these deposits suggest that the muscovite content of the fine sands is distributed uniformly and in small amounts, usually 2 to 3% with slightly more in the estuarine fine sands. Coarser, poorly sorted deposits, which are bimodal mixtures of sand and fine gravel, exhibit significant enrichment in mica. The stream deposits, regardless of their specific textural class, though they are usually coarse grained, also possess larger amounts of mica than do the offshore sands. Moreover, the transition from deposits containing little mica in the bay and estuaries, to the stream and eroded shore deposits is a sharp one. A similar sharp change exists between the well sorted fine sands and poorly sorted, coarser deposits in the bay proper.

Chlorite. The only other phyllosilicate, or " clay " structure mineral, present in quantities above the X-ray diffraction limit for gross analysis is chlorite. Although minor lattice variations in this 14 Å mineral do occur, the chlorite present in Cardigan Bay deposits is, crystallographically at least, the same throughout the area. Such a conclusion is based on its 001 (14·12 Å) and 003 (4·71 Å) reflections, and 002 (7·06 Å) and 004 (3·53 Å) reflections.

Major fine sand deposits offshore, excepting the 2 km. wide zone off the Borth beach, contain less than 5% chlorite and have a mean of about 3%. There are no pronounced trends within these find sand deposits as chlorite seems to be a ubiquitous component. Increased percentages of chlorite are reported for a zone extending about 2 km. offshore, and parallel to the coast from Borth northward to about the mouth of the estuary. Sand in this relatively restricted area (Text-fig. 2) contains amounts of chlorite greater than 5%, but less than 10%, e.g., at Station 25, a very fine (3·1 ϕ *Mz*), well sorted (1·13 So) sand contained 8%. Chlorite progressively decreases in littoral sands with increasing distance northward from the contact of the Borth beach with the eroded cliffs. These beach samples, except 152 (ϕ *Mz* 2·1), are medium-grained sands. Close inshore samples near the cliffs between Borth and Sarn Wallog (poorly sorted deposits containing coarse lithic fragments) contain abundant chlorite. Also in the southern part of this survey, a tongue-shaped zone of sediments with high chloritic content is delimited for much the same stations as those previously shown to have abundant mica present.

Excepting Stations 158A (3%) and 168 (3%), all samples from the Dyfi estuary contain chlorite in excess of 5%. Fine grained marsh deposits along the southern side of the estuary contain significantly larger amounts of chlorite than do other sediments of similar texture in the estuary (a similar situation exists for the 10Å mica distribution). Samples from the transition zone of sedimentation in the upper estuary/lower stream channel region provide evidence of an abrupt decrease of chlorite. Station 163, in the uppermost estuary, with 9% chlorite, and Station 160, in the lowermost stream channel, with 35% chlorite, exhibit a marked difference in chlorite content, even though both samples are fine sands (ϕ *Mz* 2·9) and both are well sorted (So : 1·12 and 1·20). Still farther upstream, samples collected in the vicinity of Machynlleth were found to contain about three times more chlorite than the uppermost estuary sands. All coarse grained deposits in the tributary streams on the south side of the estuary contain more chlorite than do the estuary deposits.

Deposits in the Mawddach estuary contain slightly more chlorite than do the nearby offshore fine sands. With one exception, which contained 4% chlorite, all samples in this estuary are reported to have chlorite in amounts exceeding 5%. Three local areas in the estuary, represented by Stations 136, 140 and 126, are enriched in chlorite, with 11, 11 and 13% respectively.

In general, chlorite is found only sparingly in the fine sands flooring the bay and is usually present in amounts less than 5%. It is slightly enriched in the fine sands off the Borth beach, and in the fine grained deposits of both estuaries.

Combined phyllosilicate suite. Charting of the combined mica and chlorite data is instructive, both in further definition of the dispersal pattern in the bay and in providing a clay mineral framework for comparison with the charted chemical data. Although the dispersal pattern for the combined phyllosilicate group is much the same as for the individual mica and chlorite species, it presents, nevertheless, a substantially more detailed distribution picture. Whereas the chlorite data delimit a facies off Borth extending northward only some 2 or 3 km. seaward, the combined 10 Å/14 Å suite shows a composite facies extension considerably farther seaward. Likewise, the tongue-shaped pattern of sands extending northward off Sarn Wallog are critically delimited. As expected, the Dyfi and Mawddach estuarine deposits show higher contents of platy minerals than do the fine sands offshore. Moreover, river channel deposits are much enriched, as are sediments associated with coastal and sarn erosion.

Plagioclase. The presence of Na-plagioclase was established for many of the bay deposits (Text-fig. 21). Plagioclase, as well as orthoclase, occurred frequently as very small, sub-rounded grains, and because of this textural relationship, i.e., smaller in size than its host quartz, the use of gross X-ray diffraction analysis for establishing feldspar abundance is preferred. For most of the fine sands in the bay, the plagioclase content is less than 5 %, the mean being between 3 and 4 %. A zone of deposits containing over 5 % plagioclase extends northward from the base of the cliffs between Borth and Sarn Wallog. Inasmuch as the deposits in this particular area range in size from very coarse "sands" (near the base of the cliffs) to very fine and fine sands (offshore), plagioclase distribution here may not be totally size dependent; indeed, some plagioclase is known to be contained in rock fragments.

Excepting Stations 154 (4%), 158A (4%) and 165 (2%), sediments in the Dyfi estuary contain plagioclase in excess of 5 %. Unlike the major contrast in the phyllosilicate abundance between estuarine and stream deposits, the upper estuarine deposits (Station 169, 6 %) contain much the same amount of plagioclase as do the Dyfi stream sediments and nearby tributaries. Bottom sediments northwest of Towyn also exhibit a slight increase in plagioclase content. Similarly, off the eroding cliffs northwest of the Tal-y-garreg beacon, plagioclase increases slightly (Text-fig. 21).

Mawddach estuary deposits, like those in the Dyfi, contain more plagioclase than do the immediate offshore sands. A slightly enriched zone extending from the mouth of the Mawddach estuary seaward in a southwesterly direction (Stations 93, 92, 91 and 41) suggests that some plagioclase might be in transport there. An irregularly outlined zone of sediment containing plagioclase in excess of 5 % occurs adjacent to Sarn Badrig. The increase in plagioclase in this area is related to active erosion of the sarn and to a source farther north, perhaps in the Tremadoc Bay area. One sample with 20 % plagioclase content was collected from the stream bed at Dolgellau. The abundant plagioclase found there does not seem to be related to the overall pattern, since deposits in the uppermost Mawddach estuary are not proportionately enriched. Station 137, however, does contain 28 % crystalline rock fragments.

In summary, plagioclase content of the bay sands is less than 5 % at most stations, except off Borth and adjacent to Sarn Badrig (5 to 10 %). Estuarine and stream deposits show plagioclase values between 5 and 9 %.

Orthoclase. Text-fig. 22 shows that there are two regions of modest enrichment of orthoclase in the bay. A bipartite area of sediments having over 4 % orthoclase extends southward from off Towyn to just north of Sarn Wallog. Accumulation of orthoclase in these sediments may be controlled, in part, by the texture of the host fraction, as the finest sands are abundant here. Farther seaward, orthoclase is randomly dispersed. The only other area in the bay where orthoclase is present in quantities of 4 % or more is the elbow-shaped zone extending from off Ty-wen northward to the vicinity of Station 120, thence southwesterly along the edge of

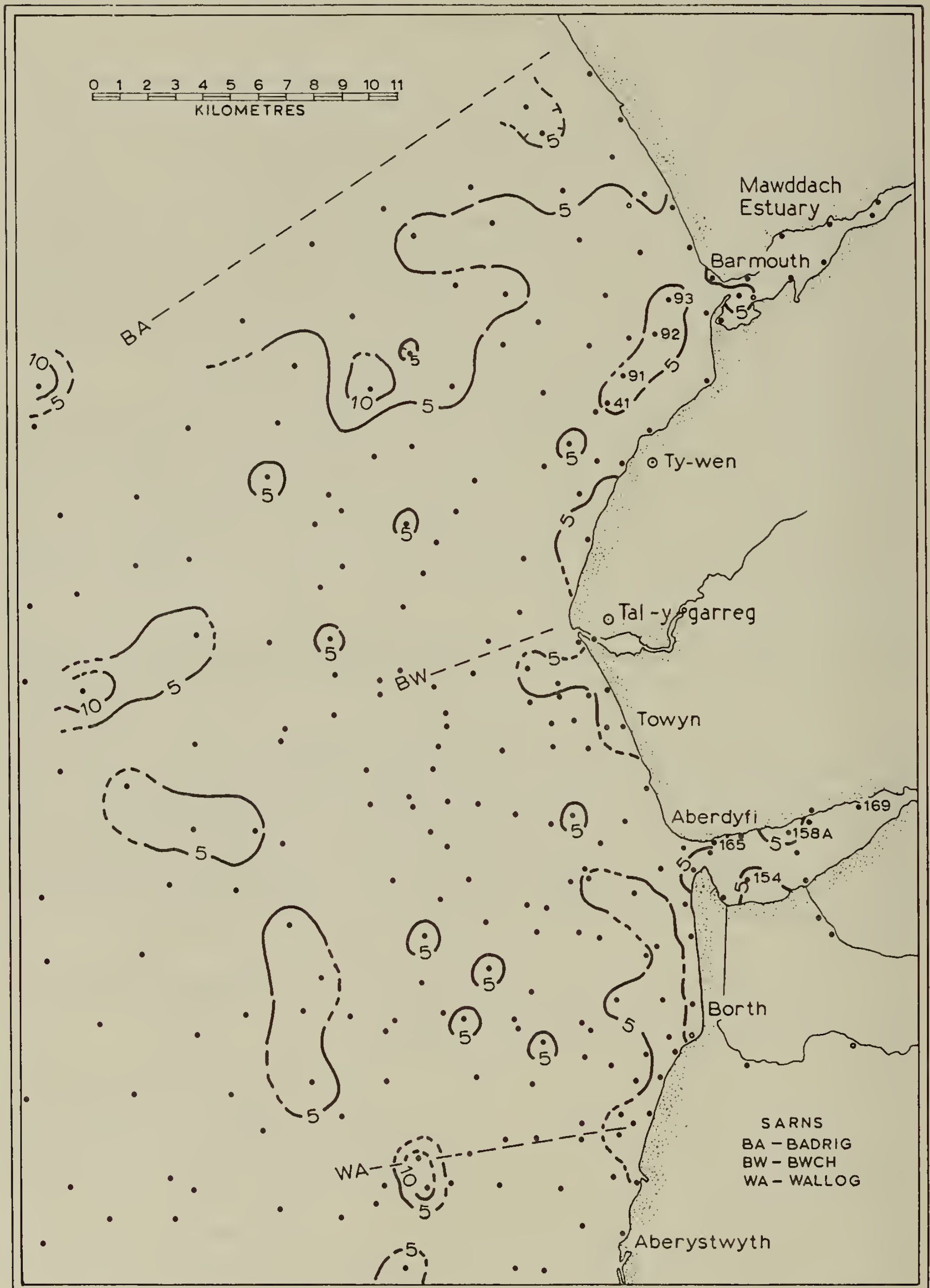

FIG. 21. Distribution of Na-rich plagioclase based on X-ray data. Contour interval 5·0%.

Sarn Badrig. Here again, K-feldspar dispersal may, in part, be texturally controlled, and more related to fineness of the sands (Text-fig. 3) than to localized introduction from some nearby source.

Only two samples from the Dyfi estuary were found to contain as much as 4% orthoclase, and none of the stream deposits in the Dyfi province contained over 3% K-feldspar. A similar situation exists for the Mawddach estuary and stream deposits.

Quartz. Diffraction data for total quartz (the dominant mineral) are reported, but since the distribution of its petrographic varieties has been discussed in detail earlier in this report, it is not reviewed in this section.

Calcite. Occurring predominantly as bioclastic debris, calcite is rather evenly distributed in the fine sands of the bay, for which values between 5 and 10% are reported. The only deposits containing less than 5% calcite are: (1) the trans-littoral neritic sands along and within a kilometre or two of the coast, (2) an elongate area about 10 km. west of Aberdyfi, and (3) a tongue-shaped zone extending westward from Borth. Although *Scrobicularia* shells are found in some of the estuary deposits, no noticeable concentration of calcite is observed there. On the south side of the Dyfi estuary, slightly higher values for calcite are reported than for deposits on the north side. Calcite was not found in any of the stream deposits associated with either estuary. Sediments with calcite in excess of 10% are found north of the end of Sarn Wallog and are associated with poorly sorted, coarse sands. The increase there is attributed to relatively abundant shell fragments.

Other Minerals. For a very few samples, faint traces of peaks for pyrite and hornblende were noted on the diffractograms. It is estimated they would represent 1% or less of the sample. Petrographic study shows that these are related to rock fragments. A very faint indication of the 2·89Å peak for dolomite was found on many diffractograms. Dilute HCl treatment was given to a number of the samples, and the 2·89Å peak disappeared on subsequent analysis, confirming the carbonate relationship. Dolomite data are reported as 1%, since abundance values cannot be determined below this limit. (See appended data for Aberystwyth grits samples in reference to the probable source of detrital dolomite.)

(*b*) *Phyllosilicate relationships*

A plot of chlorite and mica data (Text-fig. 23) shows that a common relationship exists between these two phyllosilicates. In fact, an approximate 2 : 1 chlorite/mica ratio is common for many bay deposits, regardless of their texture or their location. Although the diffraction data were plotted one with another, for the various minerals, chlorite and mica were the only two minerals which showed a clearly defined regression. Petrographic evidence confirms this finding.

It is clear from Text-fig. 23 that the reference rocks (Table I) from mid-Wales plot reasonably close to the regression trend for the bay sediments. Some scatter is seen, however, for several of the rocks. It is not likely, nor would it be reasonable to suggest, that 26 reference rocks represent proportionate coverage of the proven-

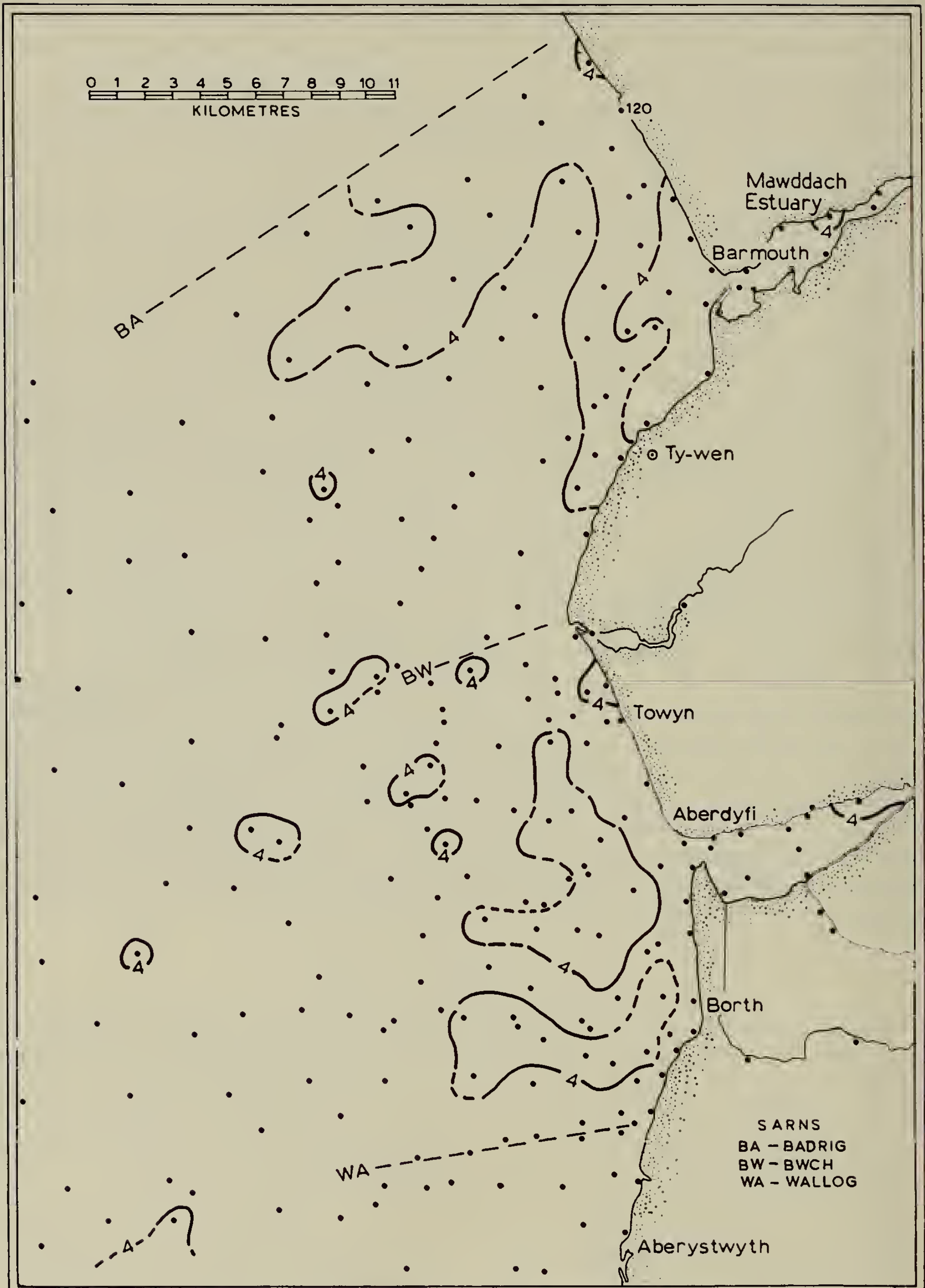

FIG. 22. Distribution of orthoclase based on X-ray data. Contour interval 4·0%.

ance. However, if the various rocks with both greater and lesser quantities of mica (relative to the regression) were to be eroded equally, and equally mixed in the bay with the others, the average ratio of the detritus would be very near that established by the regression.

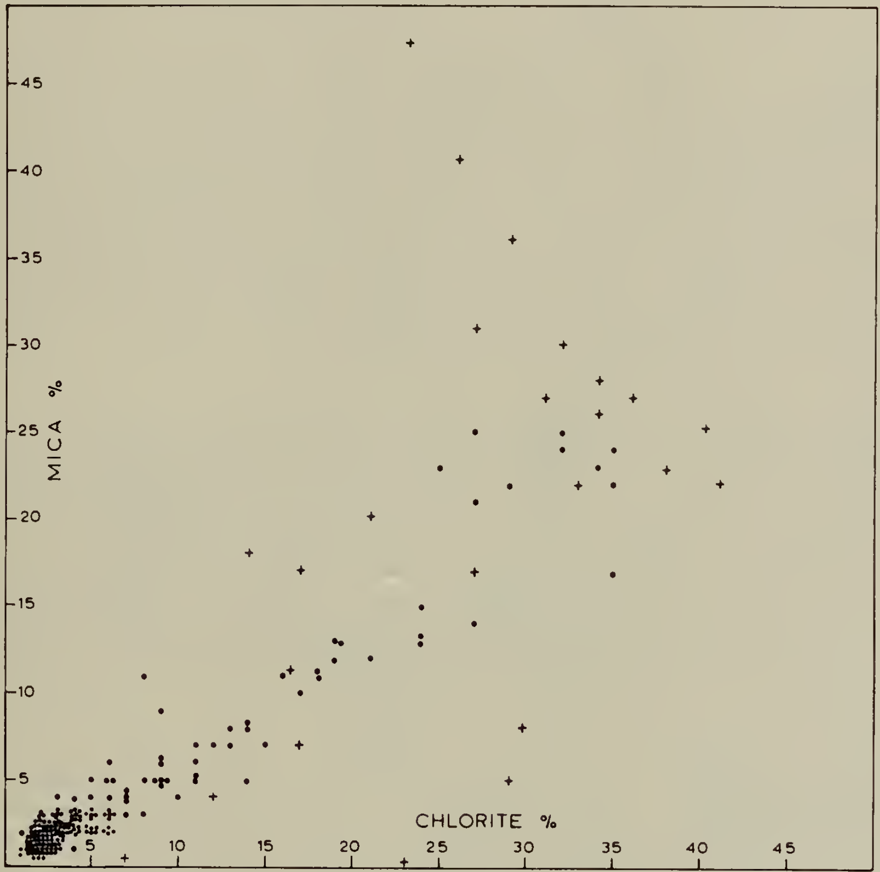

FIG. 23. Correlation of chlorite with muscovite for Cardigan Bay sediments (dots) and for reference rocks (crosses) from mid-Wales. Note the linear relationship for the bay sediments and many of the reference rocks. See text for discussion.

Although the mica-chlorite plot shows that a few sediments in excess of 20% mica are displaced from the trend, and might be interpreted as the result of lattice variation resulting from diagenesis after entering the bay, the author does not believe that the data are sufficient in number to recognize such alteration. In short, the chlorite/muscovite ratio for combined clastics provides additional support for the premise that these sediments are largely of local derivation.

VII. DISTRIBUTION OF ELEMENTS

Although the interplay of several factors such as the relative proportion of detrital material, variability in the composition of the argillaceous material, and the sulphide, heavy mineral and organic content affect the trace element content of sediments (Carr & Turekian, 1961, p. 42), it is nevertheless possible, by charting the data for the several elements, to obtain a reasonable interpretation for their distribution. Vectors have been drawn on the charts so that a composite chart (Text-fig. 34) could be prepared, and sources as well as areas of enrichment have been noted.

Aluminium. Extending northwestward and in part landward from the seaward extremity of Sarn Wallog is a wide tongue-shaped zone of bottom sediments which contain alumina in excess of 4%. This correlates with the distribution pattern of coarse clastics (Text-fig. 3), and establishes a lithic fragment/alumina relation. A narrow zone of sands with alumina in excess of 4%, related both to feldspar and to lithic fragments, extends northward from the cliffs at Borth. Between Towyn and Sarn Bwch, alumina-bearing sediments reflect the known dispersal of lithic material in that area. Additional evidence that alumina is related to the dispersal of rock fragments is found in the western mid-bay region, where the higher alumina content is related to the lithic fraction of the sediments.

Barium. This is a normal constituent of feldspars and phyllosilicates, and is preferentially distributed in Cardigan Bay. In the southern part of the survey (Text-fig. 24), a distribution pattern of Ba (over 100 ppm) suggests that the cliffs at Borth and the outer edge of Sarn Wallog are sources of Ba-bearing detritus. In the northern part of the survey, Ba rich sediments are derived from the glacial debris exposed near Ty-wen, and some are transported in a northeast trend zone. The latter are related to the bathymetric salient (Text-fig. 2) already established there. Although both river deposits and marsh deposits are enriched in Ba, there is no apparent transport of the Ba-rich sediments seaward from the estuaries. Moreover, most well sorted beach sands are low in Ba, relative to offshore deposits.

Boron. This element is present in all analysed samples ; with one exception, it occurs in amounts exceeding 20 ppm. Furthermore, the data suggest that there are two definite zones of boron enrichment. The distribution of these two areas (Text-fig. 25) is such that concentration of boron-rich sediments occurs relatively near the coast in fine sands, and the most pronounced of these two zones is that area encompassed by the 40 ppm contour from near Borth northward to Sarn Bwch. In the northern part of the survey, an important distribution area extends from near the coast southwestward to the terminus of Sarn Bwch. Within the Mawddach estuary, several stations exceed 40 ppm, but no systematic pattern of distribution is recognized. For the Dyfi estuary, there are two zones with sediments containing greater than 40 ppm: one on the north side of the estuary and one on the south side. Both are in marsh sands. Neither relates to dispersal centres.

Surprisingly, samples collected from the several rivers (with many lithic grains) do not show that boron is significantly concentrated in stream deposits, e.g., a river sample at Dolgellau contained 24 p.p.m., and a sample associated with the Dyfi drainage area contained 82 p.p.m., these being the two extremes for river sediments. In summary, boron, primarily in tourmaline, is concentrated in the fine sands offshore between Borth and Sarn Bwch, and in a narrow zone in the northern part of

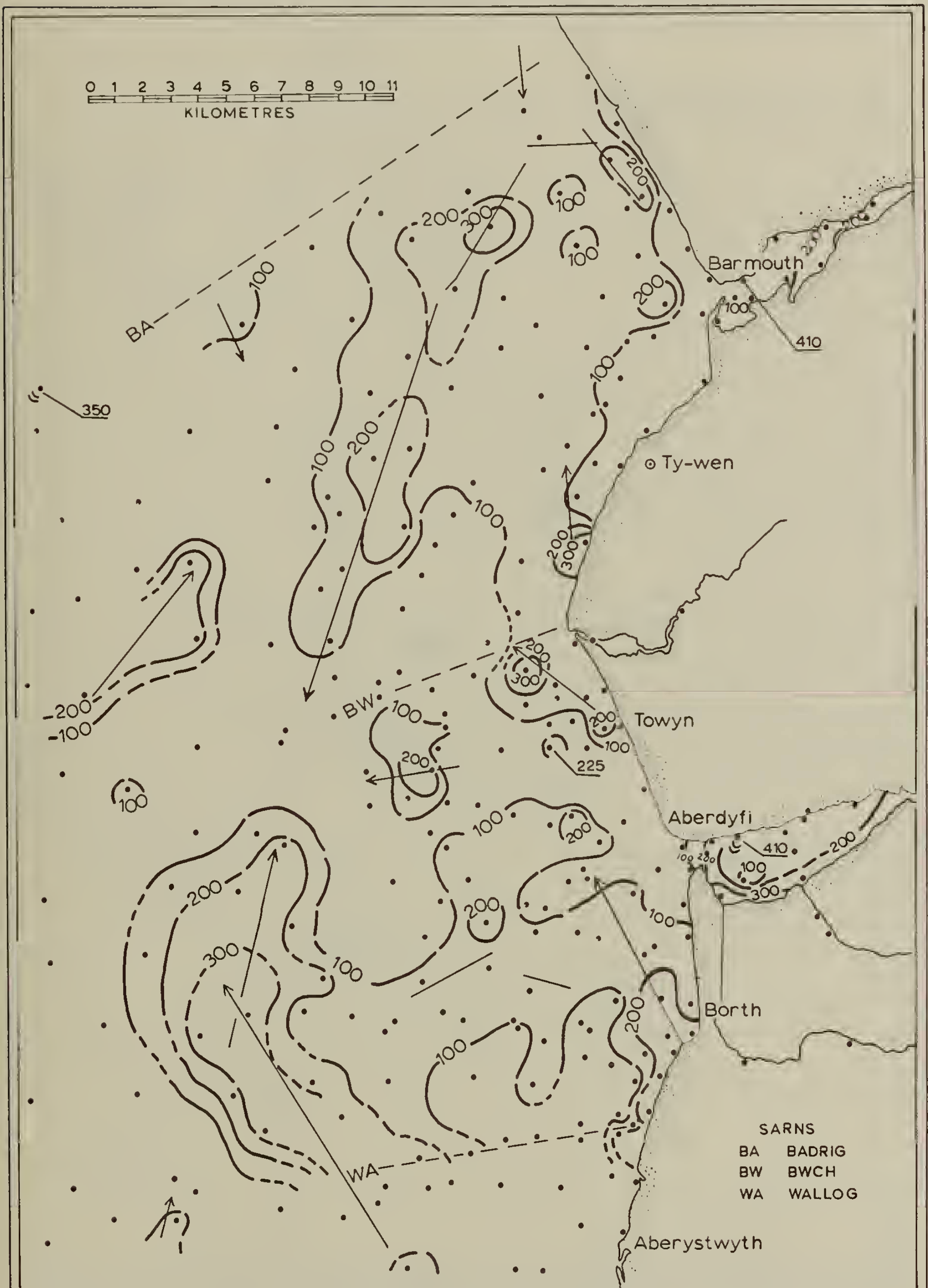

FIG. 24. Distribution of barium based on spectrographic data. Contour interval 100 ppm.

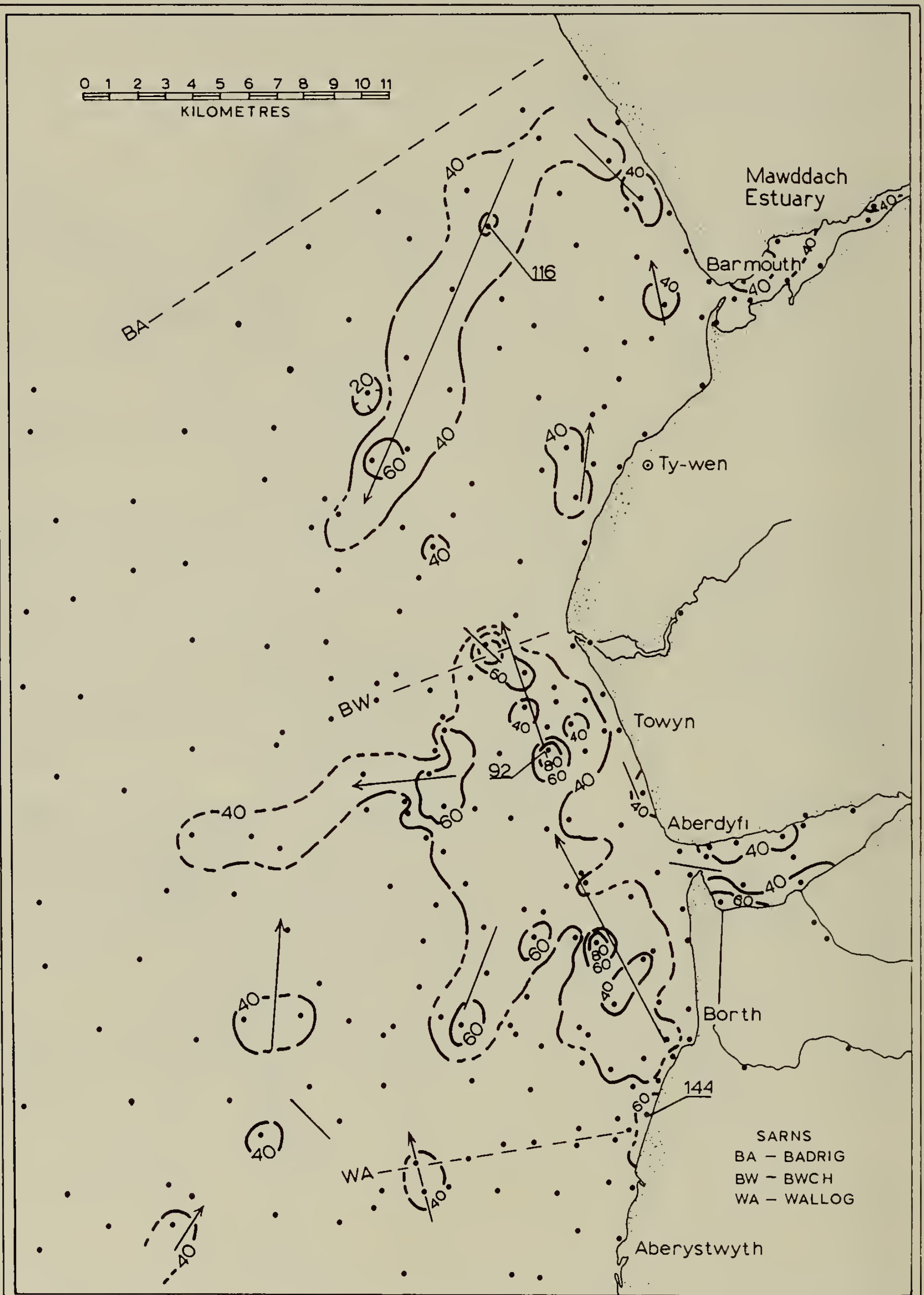

FIG. 25. Distribution of boron based on spectrographic data. Contour interval 20 ppm.

the survey. It does not appear to be related to a source associated with either the Afon Dyfi or the Afon Mawddach.

Calcium. Although some calcium is present in phyllosilicates and feldspars in trace amounts, the major portion is contained in bioclastic debris and, as such, indicates the proportionate enrichment of calcite in marine sands. Within the present survey, the amount of calcium present at any one station in the bay varies between 1·32% near Eglwys Llanaber and 9·00% some 18 km. west of Towyn. However, most of the bay sands contain less than 3% calcium and only three zones of enrichment are distributively important. These are: (1) a band of sediment containing more than 3% extending along the south side of Sarn Badrig, (2) an elongate zone extending northwest from the end of Sarn Wallog which correlates with increasing grain size and poor sorting, and (3) an area of calcium enrichment associated with coarse deposits and shell debris in the western margin of the survey. In general, calcium decreases toward the headward end of each estuary ; otherwise, there is no systematic distribution within these smaller bodies of water. Moreover, littoral sands from just north of Towyn in the vicinity of Station 174 (1·80%) northward to Sarn Badrig are noticeably deficient relative to the offshore deposits in that they contain less than 2% calcium. Obviously, it is not useful as an indicator of provenance for these bay sands, since carbonates are not found nearby.

Cobalt. With the exception of those deposits associated with coastal and sarn erosion, cobalt is not concentrated in these marine sediments. In fact, for the region as a whole, there is little variation between the various offshore stations, and no cobalt dispersal pattern is reported. The contrast in distribution of cobalt between river sediments and nearby estuary sediments should be noted, however. Cobalt values for river samples associated with the Mawddach are considerably higher than the associated estuary sediments. The same is true for the Dyfi. Thus, estuary and river sediments are apparently unrelated.

Chromium. The major zone of chromium enrichment extends from the cliff area south of Borth northward, terminating some 4 km. west of Aberdyfi (Text-fig. 26). At this point, a narrow zone of chromium-rich sediments is developed south-westward. Furthermore, fine sands with high chromium values are transported across Sarn Bwch, and no interruption of the distribution plan occurs in the vicinity of the sarn. Another major distribution within the southern half of this survey occurs as a belt extending northward from the outer end of Sarn Wallog. This pattern follows a zone of coarse grained, poorly sorted detritus (Text-fig. 6). Only one distribution area of importance is noted in the northern half of the survey. This, an elongate, narrow zone extending diagonally across the inshore fine sands, is defined by Station 237 (87 ppm) at one extremity, and Station 101 (83 ppm) at the other.

No evidence is available to suggest that chromium distribution is associated with the Mawddach and Dyfi estuaries, although slight enrichment in the marsh deposits is reported. On the average, a two- to three-fold increase over the offshore sands is noted for river deposits. In conclusion, sediments enriched in chromium (over 50 ppm) are restricted, as major distribution areas, to a narrow mid-bay belt in

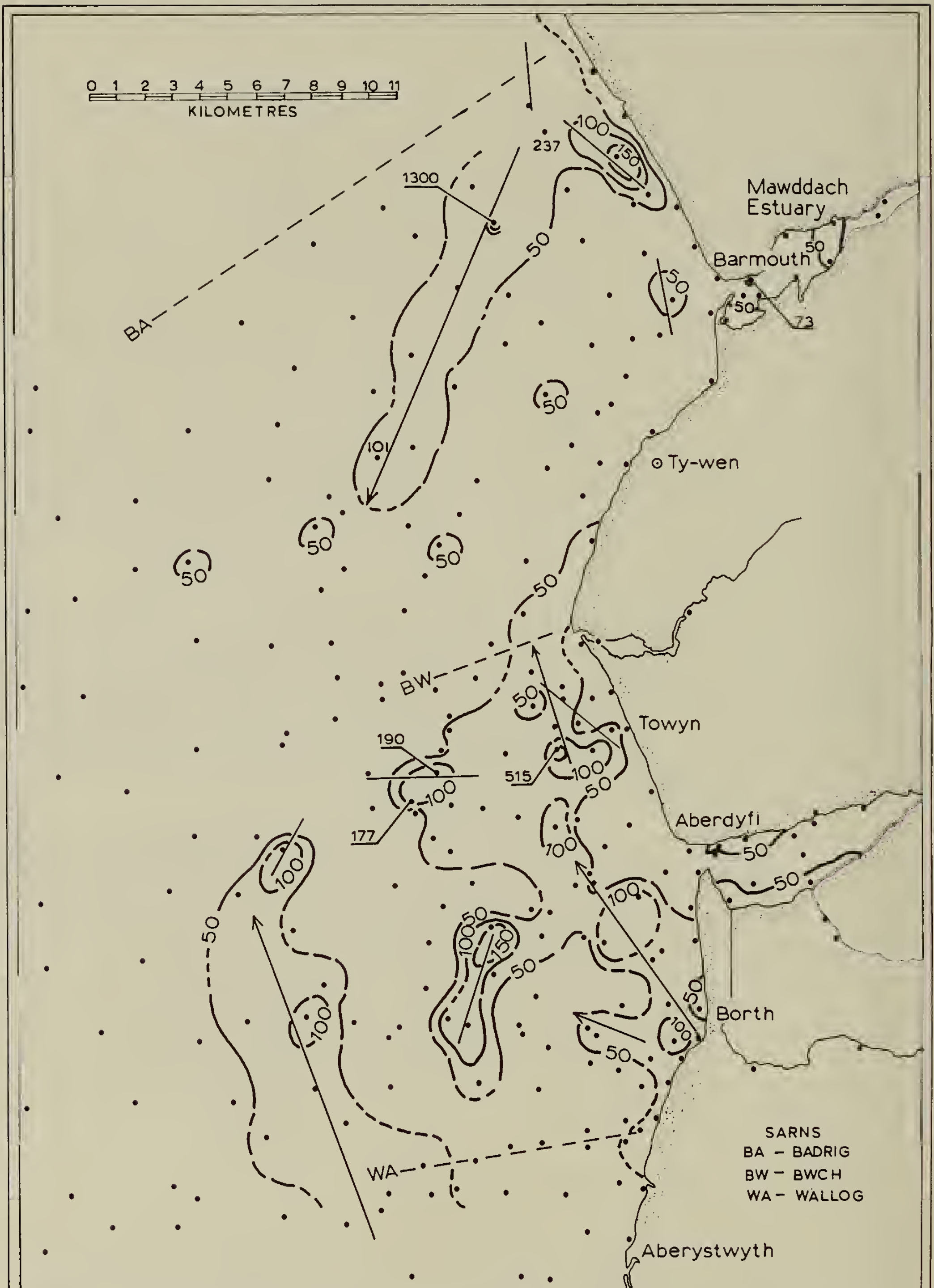

FIG. 26. Distribution of chromium based on spectrographic data. Contour interval 50 ppm.

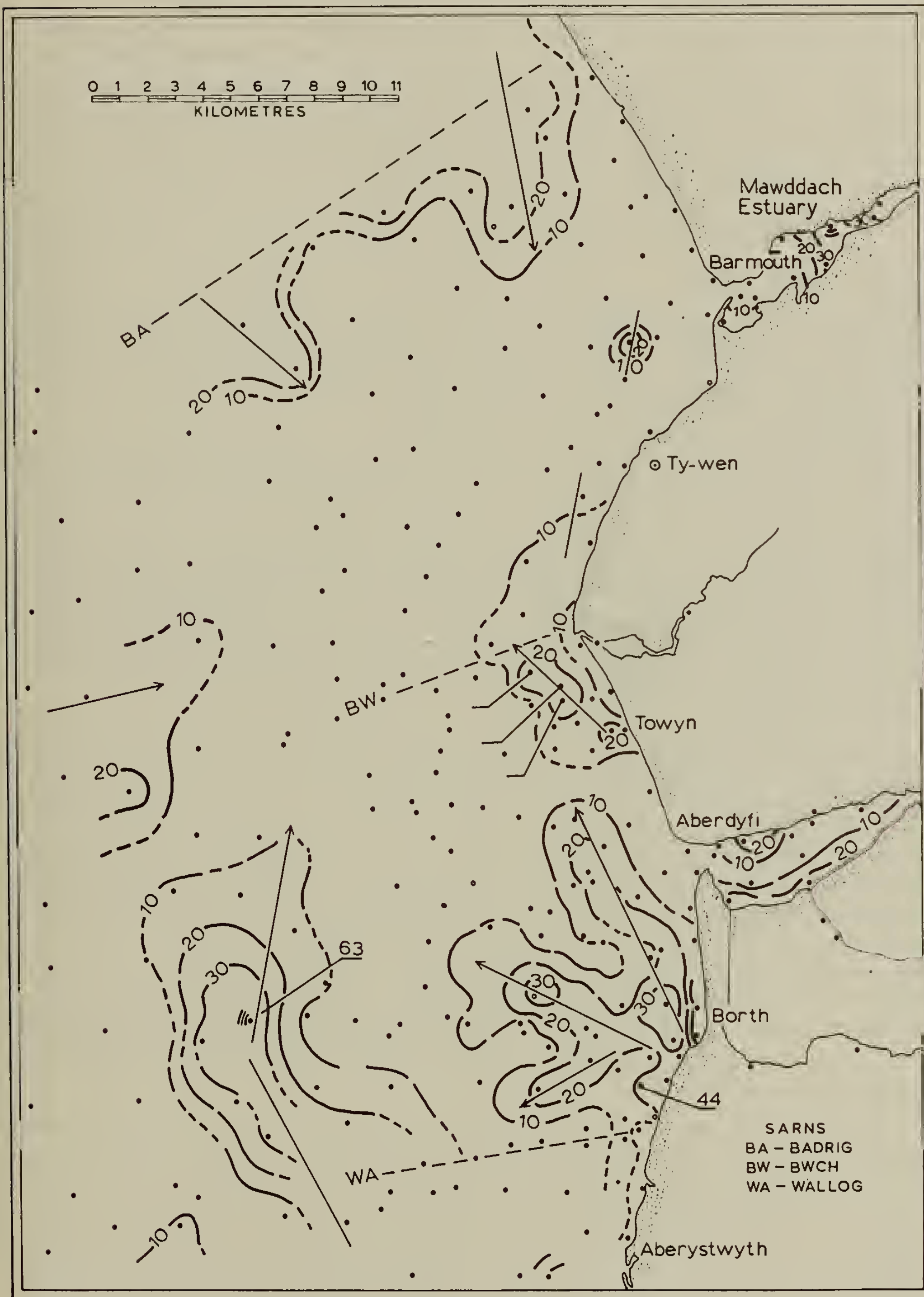

FIG. 27. Distribution of copper based on spectrographic data. Contour interval 10 ppm.

the north part of the survey, to a narrow belt extending north from Sarn Wallog, and to an irregularly shaped zone extending northwestward from the cliffs at Borth.

Copper. One of the most rewarding of the several charted element distributions is that for copper (Text-fig. 27). The distribution of sediments enriched in copper, i.e., over 10 ppm, is basic to understanding the distribution of nearshore sands within the survey and to locating those areas offshore with sands which owe their origin to local provenance.

A definite distribution is charted for three lobe-shaped zones extending seaward from the cliffs near Borth. Within this distribution area several samples are reported with values exceeding 20 ppm Cu. Likewise, littoral samples along the coast between Sarn Wallog and Borth are high in copper. Copper enrichment of these nearshore deposits is related to the cliff exposures south of Borth. Anomalously high values are reported for the coarse grained, poorly sorted sediments extending northwestward from the end of Sarn Wallog.

A coastal zone extending from Towyn northward and beyond Sarn Bwch contains sediments enriched in copper. In fact, some of the highest reported values are for stations within this nearshore area, obviously related to the eroding cliffs of glacial debris at Towyn. In the northern part of the survey, south of the Sarn Badrig shoal near Mochras, several stations are charted with values above 20 ppm; these, as well as the general distribution of samples with less than 10 ppm in the far northern part of the bay, strongly suggest a distribution related to a source or sources beyond the limits of this survey, perhaps in Tremadoc Bay. In the Mawddach and Dyfi estuaries, several zones of enrichment occur locally, but there is no trend suggesting sources upstream.

Iron. It must be emphasized that comments on distribution relate to the total content of iron (as Fe_2O_3) in the sediments, regardless of its mineralic host. Iron remains rather constant in amount throughout most of the sand areas, being between 2 and 3 %; however, it is modestly enriched in three rather limited zones. The most pronounced of these extends northward from the outer edge of Sarn Wallog. Another area of enrichment (over 3 %) is that which parallels the cliffs near Borth and extends northward to just off the estuary mouth. Here again, a progressive decrease is noted for those stations farther from the littoral zone south of Borth. The only other area of enrichment is a small zone just northwest of Towyn. In the Dyfi estuary, iron is preferentially distributed along the south shore, but in the Mawddach estuary there does not seem to be any definite distribution plan. Considering both estuaries, neither seems to be related to sources, or to transport of the iron-bearing minerals found offshore.

Gallium. Throughout most of the study area, gallium is rather evenly distributed in amounts between 2·0 and 5·0 ppm; however, in the southern part, two zones are present where the sediments contain 5·0 ppm, or more, gallium. The first of these is that which extends northwestward from the end of Sarn Wallog. This zone shows a progressive decrease in the amount of gallium reported at stations increasing with distance from the sarn. These stations lie within a belt of coarse grained " sands ", which extend away from Sarn Badrig (Text-fig. 6), and the two distributions are related. The second area is developed as an elongate distribution of gallium-enriched sediments extending northward from the cliffs near Borth, and paralleling the nearby beach as far north as the estuary mouth.

Deposits in the Mawddach estuary do not show any recognizable distribution plan, even though certain of the samples contained gallium in amounts exceeding 10 ppm. On the other hand, sediments in the Dyfi estuary show enrichment of gallium in the marsh along the south side of the estuary. River sediments, even in small streams, reflect their high content of lithic fragments by pronounced increase in gallium.

Potassium. While potassium is present in amounts exceeding 1% in the river deposits, it is noticeably decreased in amount in the offshore and estuary sands, and only eight samples were reported to contain amounts exceeding the above value. For the survey as a whole, particularly in the fine sands, potassium is distributed in amounts less than 0·5%. Nevertheless, three zones are noteworthy, namely : the zone extending northwestward from the end of Sarn Wallog, the narrow coastal zone extending northward from the cliff area south of Borth, and the small development between Towyn and Sarn Bwch.

Magnesium. The distribution of magnesium in amounts exceeding 0·5% is limited to 15 stations in the entire offshore part of the survey. Of these, only those in the littoral zone at the base of the cliffs south of Borth, and in the zone of coarser sediments northwest of the seaward tip of Sarn Wallog are of importance. In both of these areas, the enhancement of magnesium is due to higher phyllosilicate content. In the Dyfi estuary, there are only two stations with magnesium reported in excess of 0·5%, and such limited control cannot be expected to establish any meaningful pattern there. The situation is much the same for the Mawddach estuary. In short, magnesium is present in all samples, but for most of the bay sands it shows little variation. Due to their higher lithic content, the river deposits are about three times richer in magnesium.

Manganese. The distribution of manganese (Text-fig. 28) is complex and, as such, necessitates careful consideration of its pattern of enrichment, particularly in the sands. Manganese is considerably enriched in these marine sands in comparison with certain other areas. For example, Moore (1963) reported maximum values of about 300 ppm Mn for Buzzards Bay deposits which contained much higher amounts of phyllosilicates. In the present study, however, even well sorted, fine grained, non-argillaceous sands include manganese in excess of 500 ppm.

In the southern half of the survey, two prominent areas of manganese enrichment are charted. The first of these is the tongue-shaped zone which extends northward from the seaward end of Sarn Wallog. This coincides with the known distribution of mixed coarse lithic fragments and sands and is delimited by the 400 ppm contour The second is also outlined by the 400 ppm contour and constitutes a major offshore enrichment zone extending from the cliffs near Borth northward to the vicinity of Sarn Bwch. This area, however, contains some of the finest sands (Text-fig. 3) as well as some of the best sorted ones (Text-fig. 6).

In the northern part, an elongate area of fine manganese-enriched sands occurs.

Fig. 28. Distribution of manganese based on spectrographic data. Contour interval 100 ppm.

With one exception, all of the samples within a 5 km. radius of the mouth of the Mawddach estuary at Barmouth are reported to have less than 500 ppm manganese. Indeed, the littoral samples between Ty-wen and Eglwys Llanaber are noticeably deficient in manganese as none contains more than 300 ppm.

The data do not show that a systematic distribution of manganese exists within the Mawddach estuary. On the other hand, sediments in the Dyfi estuary are enriched both along its south shore as well as in the immediate vicinity of Aberdyfi. River samples associated with streams draining into the estuaries are deficient in manganese when compared with the marine sands.

Sodium. The distribution of sodium expressed as salients is limited to three areas : first, a band of sediments extending north from the outer end of Sarn Wallog ; second, a band extending northward from the vicinity of Borth ; and, third, a small area of concentration off Towyn. For the rest of the northern part of Cardigan Bay, there is no pronounced geographic pattern to the distribution of sodium, and for most stations values between 0·30 and 0·50% are reported.

Nickel. At only one station does nickel occur in an amount less than 10·0 ppm, and although, for most of the bay, nickel is present in the sediments in amounts between 10 and 20 ppm, four areas of pronounced nickel enrichment are known (Text-fig 29). First, an area delimited by the 20 ppm contour extending northward from the end of Sarn Wallog is of local importance, and correlates with known coarser grained sands. Second, a narrow zone extending northward and paralleling the coast is developed between the cliffs south of Borth and the mouth of the Dyfi estuary. Third, a local zone of enrichment occurs inshore between Towyn and, crossing the sarn, the vicinity of the eroding cliffs north of Tal-y-garreg. Fourth, a distributive zone extending south from the shoal end of Sarn Badrig has been charted.

Lead. Four major zones of enrichment occur in the northern part of Cardigan Bay (Text-fig. 30), which provide clues to the origin and distribution of bay sediments. The most well defined area of lead accumulation is that which extends northwestward from the cliff exposures near Borth. The contours bifurcate, suggesting that, while the lead is related to a common source, it is distributed in two directions, reflecting variations in the local tidal current regime. Correlating with increased grain size and poorer sorting, a second zone of enrichment extends northward from the seaward end of Sarn Wallog. Though the geochemical discussion of lead is presented later, it may be pointed out here that this same area is also one with higher amounts of phyllosilicates. Extending northward from Towyn and beyond Sarn Bwch into the middle of the north part of the bay is another zone in which sediments contain this trace element in amounts exceeding 20 ppm. The distribution of lead in this area indicates that sands entering the bay near Towyn are transported northward over the shoaling, landward end of Sarn Bwch. A zone of enrichment, probably associated with tidal currents and transport from beyond Sarn Badrig, occurs in the far northern part of Cardigan Bay.

Littoral sands on either side of the estuary mouth at Barmouth are noticeably deficient in lead, as all samples collected close to the coast, except one, contained

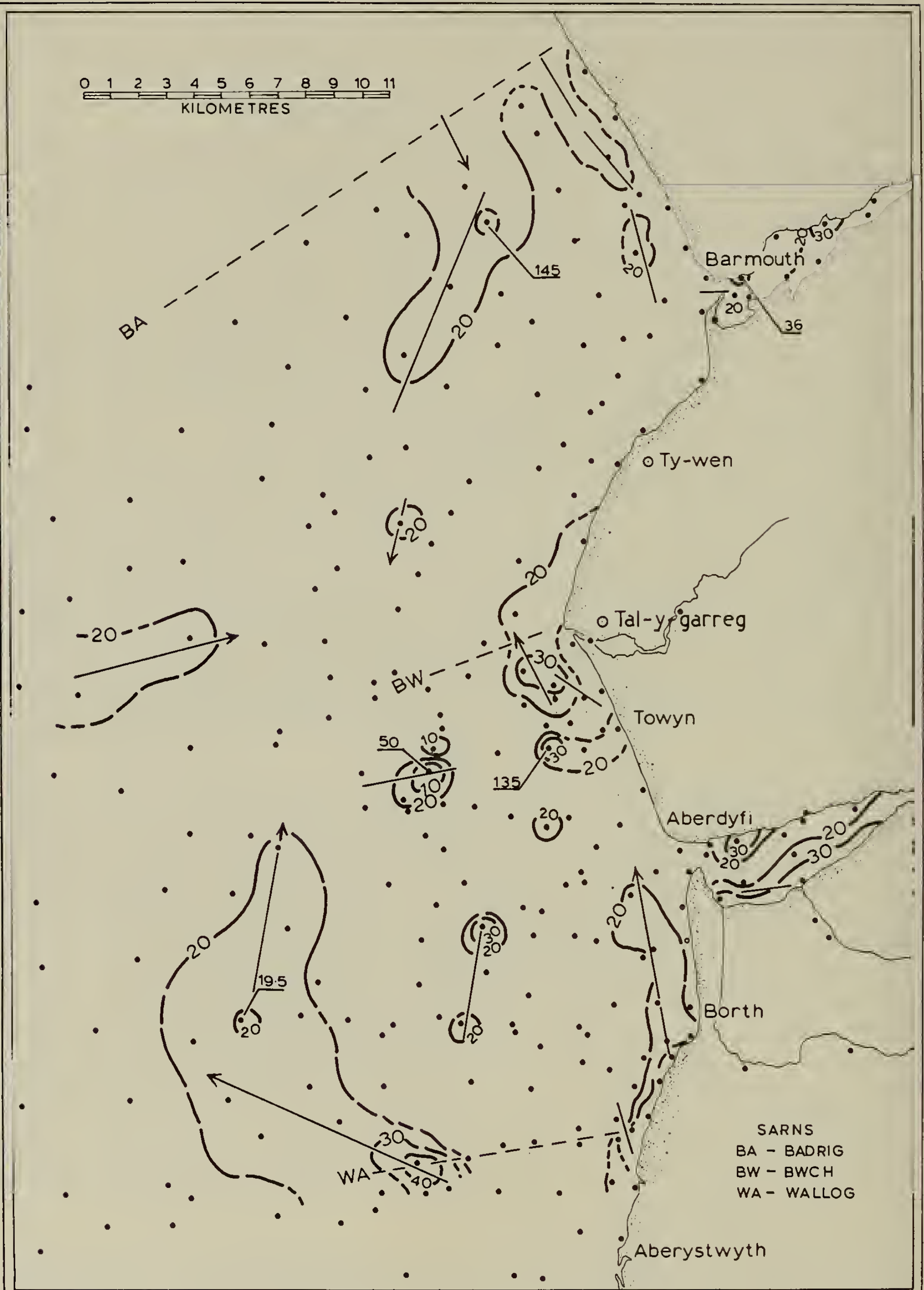

FIG. 29. Distribution of nickel based on spectrographic data. Contour interval 10 ppm.

FIG. 30. Distribution of lead based on spectrographic data. Contour interval 10 ppm.

less than 10 ppm Pb. In the Dyfi estuary lead is present in amounts exceeding 40 ppm in the marsh deposits along the south side of the estuary. Sediment samples collected from the nearby Afon Leri and Afon Clettwr were analysed and found to contain lead in amounts between 118 ppm and 186 ppm, thus more than twice the amount reported for the marsh deposits near their mouths.

In summary, the major areas of lead concentration are related to coastal erosion, to coarse lithic grains eroded from Sarn Wallog and to an, as yet, unidentified source near Sarn Badrig.

Scandium. Over most of the offshore survey, scandium occurs in amounts between 4 and 10 ppm. Nevertheless, three areas where scandium exceeds 10 ppm are important to understanding sediment sources. The first of these is located adjacent to the coast in the vicinity of Borth. The second is the tongue-shaped area extending northward from the seaward end of Sarn Wallog. Within this area, only two stations (190 and 14) contain more than 10 ppm; however, several other stations approach this value. Thirdly, northwest of Towyn, Stations 62, 33 and 34 are reported with values exceeding 10 ppm, and, as such, the area, although small, is important. Although several samples from the estuaries have values in excess of 10 ppm Sc, there is no evidence seaward of the estuary mouths that scandium is transported in sands through the estuaries and into the bay.

Strontium. Strontium is enhanced in only two areas in the northern part of Cardigan Bay. The first of these extends northward from the seaward end of Sarn Wallog where some of the highest strontium values are reported. This same general area is also one of sediments with abundant shell fragments. The second area of distributive importance is that located in the far north of the survey adjacent to Sarn Badrig. For most of the offshore sands, strontium is present in amounts varying between 90 and 150 ppm. Littoral sands are, however, deficient in strontium as are the sediments in the upper estuaries. Samples from river beds associated with both the Dyfi drainage area and the Mawddach network contain less strontium, on the whole, than do the offshore sands.

Titanium. Sediments containing more than 2,000 ppm of titanium are essentially restricted to two major areas (Text-fig. 31). The first is an inshore province approximately 8 km. wide which extends northward from Sarn Wallog to Sarn Bwch ; it gradually narrows after crossing the sarn and terminates in the vicinity of Ty-wen. This area is largely one of well sorted fine sands actively swept by bottom currents. The second is that elongate zone extending from Sarn Badrig in the north corner of the survey southward to near the end of Sarn Bwch. Within this narrow area are some of the highest values reported. These areas, particularly the northern one, are in regions where the sediments are deficient in phyllosilicates and, thus, much of the titanium present is related to other mineralic hosts, namely the heavy minerals. There is no pronounced distribution pattern for titanium in the estuaries. However, data for the several river samples show that titanium is present in stream deposits in excess of 4,000 ppm, reflecting, of course, the abundant

FIG. 31. Distribution of titanium based on spectrographic data. Contour interval 1,000 ppm. (values × 10^3).

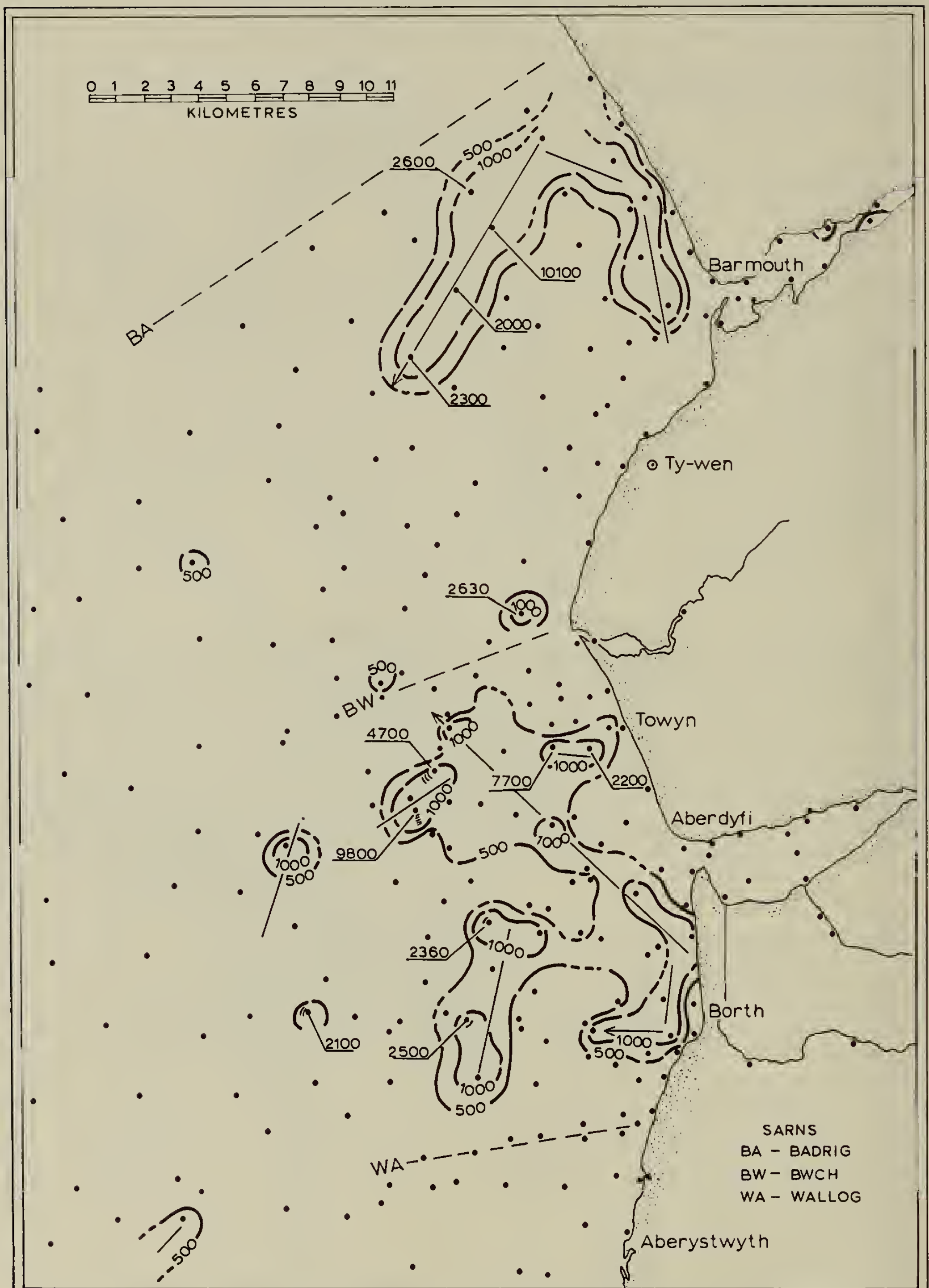

FIG. 32. Distribution of zirconium based on spectrographic data. Restricted contours of 500 and 1,000 p.p.m.

lithic fragments. In all, titanium is enhanced in current swept, well sorted, fine grained sands.

Vanadium. In seeking a reasonable concentration level for describing the distribution of vanadium, values of 60 ppm or higher are considered significant. On this basis three areas are delimited, namely : a zone extending north from the seaward end of Sarn Wallog ; an irregular zone extending northwestward from Borth, and finally a zone in the northern area of the survey adjacent to Sarn Badrig. Several samples contained more than 60 ppm vanadium, in particular those in the vicinity of Sarn Bwch, but none are believed to be significant for establishing distributive patterns. Likewise, data for the estuary samples do not suggest any systematic distribution pattern within these smaller bodies of water.

Zirconium. The charted distribution of zirconium (Text-fig. 32) shows that while this trace element is present at all stations, it varies within extremely wide limits. From a low of 51 ppm to a high of 10,100 ppm, it would first seem that the spread of data is too great to be used in establishing any logical distribution system. None of the minerals determined by X-ray diffraction shows such a proportionately wide range ; nevertheless, by selecting the 500 p.p.m. contour as a minimum line of distributive significance, it can be shown that zirconium is enriched in two areas. The first of these is an irregularly shaped area which extends northwestward from Borth and is related to fine, well sorted sand. The second area is located in the northern part of the survey, bounded by the inshore part of Sarn Badrig and the coast between Barmouth, and the terminal end of this same sarn. The area forms, in outline, an inverted U-shaped zone.

Data for the several estuary stations do not establish any local distributive patterns. Since the data for the several river samples do not exceed 255 ppm, it may be assumed that, on the whole, offshore sediments are much enriched in this trace element in comparison with the river and estuary deposits; that zirconium is high in these bay deposits in general, and that zirconium enrichment is indicative of high energy sedimentation.

VIII. DISCUSSION

In the previous pages of this report Cardigan Bay sediments have been described in terms of their textural, petrographic, mineralogical and chemical characteristics, and individual dispersal and distribution patterns have been deduced from these data. Attention must now be given to significant inter-parameter relationships, and the environment of sedimentation. Composite dispersal and distribution charts show the general sedimentation pattern, as well as the significant factors which have locally influenced it.

In this study some comparisons are necessary, and consequently data for other Recent sediments, as well as some Welsh reference rocks (Tables I and II) have been included. No attempt has been made to compare trace-element and mineral data for which there is no textural information, or equivalent reference of comparison. It is, for example, meaningless to seek similarities of element abundance between coarse grained shallow water sands and abyssal clays. The following topics are selected examples and many further studies may be made from the reported data.

(*a*) *Sediment Dispersal*

The overall dispersal of sediments in northern Cardigan Bay is clearly shown by a composite dispersal chart (Text-fig. 33). The most obvious dispersal trend is that extending northward from the cliffs at Borth ; this suggests that numerous grain types are transported northward from this local source. Furthermore, transport continues northward past the mouth of the Dyfi estuary and along the coast west of Aberdyfi. Of importance is the fact that several dispersal/transport vectors charted for the Dyfi estuary mouth suggest that several grain types enter the estuary from the bay. Furthermore, Dyfi estuary data suggest that some fine sand is transported up the estuary and that some is deposited along the south shore of the estuary. Locally, minor transport zones totally within the estuary may exist, and the erosion of exposed rocks along the north shore could provide a source for the small amount of grains apparently introduced there. The significant observation is that there is no great dispersal from the estuary into the bay.

For the area north of Aberdyfi, in the vicinity of Towyn, the network of vectors suggests that the eroding cliffs at Towyn are important local sources of detritus. These vectors, chiefly oriented north or northwest, show that the dispersal of introduced detritus is in that general direction. Furthermore, at least four vectors show that sand is being actively transported over the shoaling end of Sarn Bwch. The proximity of vector terminations in the vicinity of the sarn suggests that this same situation may well occur for several other lithic and quartz grain types. Some sand is transported in a westerly direction, and may in part be passed around the end of Sarn Bwch and in part be transported seaward.

North of Sarn Bwch, dispersal vectors reveal that at least ten types of grains are dispersed from the vicinity of the eroding cliffs along that part of the coast (Text-fig. 33). In this general vicinity, but seaward some 3 km., a trend of northward transport is apparent. This continues uninterrupted northward along the coast, passing offshore from Barmouth and the mouth of the Mawddach estuary. Only four vectors are charted for sediments within the Mawddach estuary itself. Three of these represent sands transported into the estuary from the bay, and one represents dispersal from the estuary seaward. It is important that there is no obvious alteration of the prevailing northward transport pattern immediately offshore from Barmouth. If any significant amount of detritus were being delivered seaward, it would have been charted and its presence recognized. Northward beyond Barmouth, the composite dispersal parallels the coastline; however, in approaching the shoaling Sarn Badrig region, dispersal vectors show that, in part, transport is to the west. In this same region, several vectors suggest that some sand is entering from beyond Sarn Badrig and is being introduced into the established distribution system, even while a minor amount of sand is dispersed northward and close to the shore. That this is the case is further substantiated by the known accumulation of sand along the coast between Eglwys Llanaber and Mochras Point.

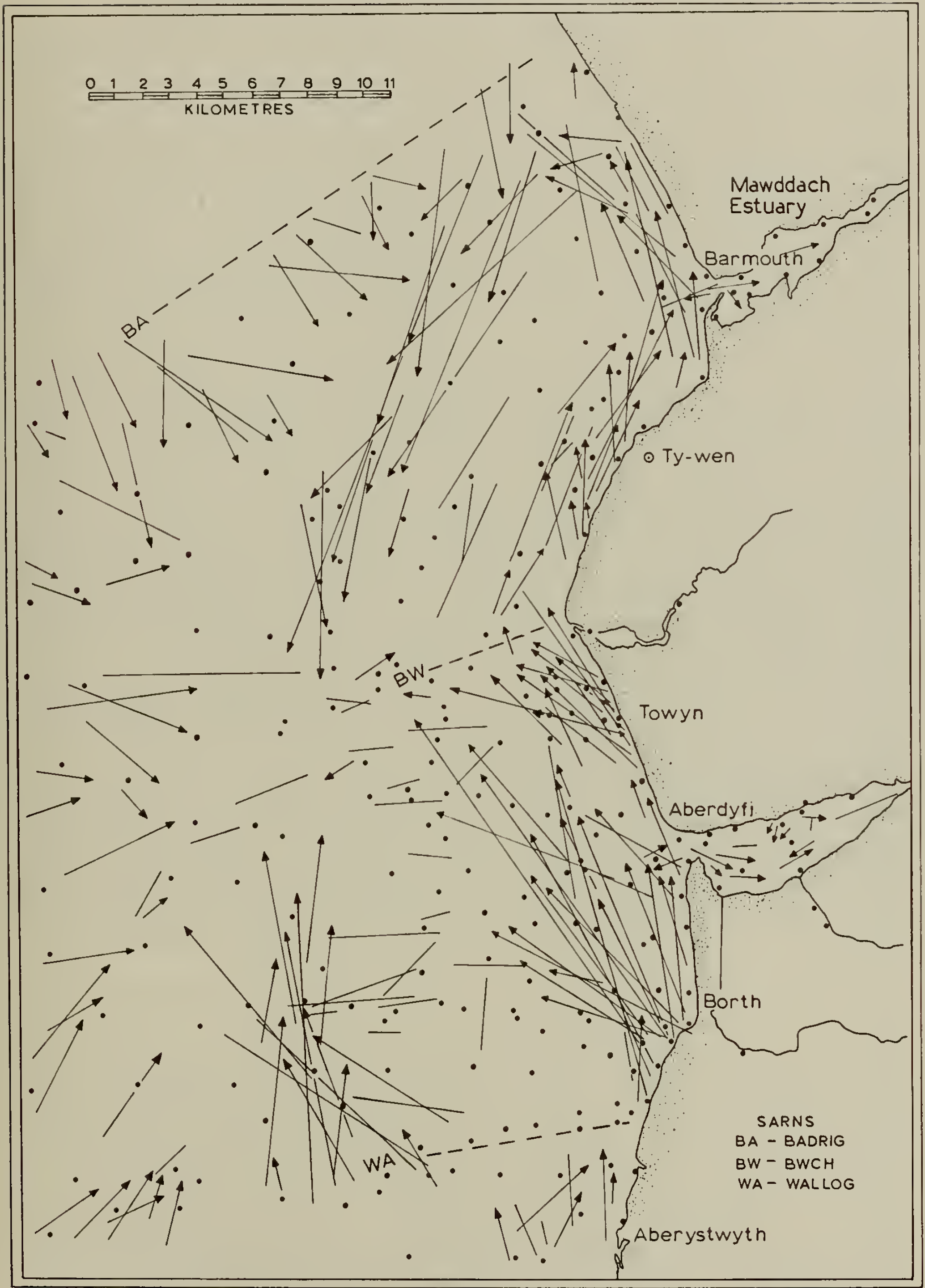

Fig. 33. Chart showing dispersal vectors for each of the petrographically determined grain types.

A major zone of sand dispersal is established in the middle of the bay (Text-fig. 33). This narrow area is considered one of the most active transport zones within the survey. It is, furthermore, related to the shoaling bathymetric salient (Text-fig. 1) for this region, which, in turn, reflects the net accumulation of detritus there.

For the western margin of the present survey, dispersal vectors show a diminution eastward, i.e., dispersal from a source seaward. However, firm conclusions regarding this far western overlap zone must await subsequent studies beyond the charted limits of the present survey, and it must be remembered that much of the area west of the sarns is composed of somewhat coarser clastics (Text-fig. 4). Eastward diminution in this region of coarser sediments could be a reflection of simple mixing of coarse detritus with the abundant fine sands found closer inshore ; the data are not conclusive.

In the southwest corner of the region, six vectors all very nearly parallel, are evidence that some sand is introduced into the area from the south, and beyond the seaward terminus of Sarn Wallog. Also, in the vicinity of Sarn Wallog, numerous vectors with " greater-than-average " magnitude are charted for a narrow zone extending northward from the end of this sarn. Since several of these are for lithic grains, it appears most reasonable to explain this zone as one of dispersal and transport away from the outer eroding terminus of the sarn. An alternative explanation, which may be substantiated only by study of deposits south of this survey, is that some of these grains are transported around the end of the sarn from a source, or sources, south of Aberystwyth. That some sand is transported over Sarn Wallog from the south is evident from the vectors west of Aberystwyth.

A number of east/west axial trend lines occur in the middle part of the chart. Although several of these may be interpreted as westerly-pointing vectors they are designated simply as zones of transport.

In summary, the composite dispersal plan for the grain types (Text-fig. 33) reveals that the sands in northern Cardigan Bay are current transported in a definite and orderly pattern. Briefly, their movement is northward along the coast to near Sarn Badrig, thence south/southwest to the vicinity of the middle part of the area. Sands are also introduced from beyond Sarn Badrig and from beyond the terminus of Sarn Wallog. Moreover, the net transport of sand is into the estuaries and not out of them. The rivers contribute virtually nothing to the bay deposits.

(*b*) *Distribution of chemical elements*

By preparing a composite vector distribution chart (Text-fig. 34), the overall plan of element distribution is clearly shown ; it provides evidence of environmental and local source influences. In the absence of adequate bottom current data, the composite vector chart of chemical elements provides evidence of the effective relative magnitude of tidal currents and their direction. Obviously, chemical elements by themselves are not dispersed, but are distributed according to the dispersal of their mineralic hosts. Nevertheless, the common geochemical-mineralogical associations of most elements, including the trace elements, are fairly well understood (Rankama

& Sahama, 1950 ; Turekian & Wedepohl, 1961), and it is possible to use charted chemical data for interpreting the major distribution scheme.

As in the previous case for grain dispersal, element distribution vectors (Text-fig. 34) charted for the region just west of Borth show pronounced northward alignment. Furthermore, the vectors are largely confined, not only west of Borth, but for most of the survey, within narrow zones, much more so than are grain dispersal vectors. Vectors for the area immediately west of Towyn confirm a distribution centre and northwestward transport from there. Element vectors provide additional evidence that sediments are transported across the shoaling end of Sarn Bwch and thence northward along the coast west of Ty-wen. Vectors charted for the region of sands adjacent to the cliffs north of Sarn Bwch (Pl. 2, fig. 2) show that sediments originate there and are transported northward. Within the northern part of this survey, a pronounced transport salient parallels the coast off Barmouth and turns westward on approaching the shoaling end of Sarn Badrig, whereupon the transport zone is directed in a south/southwesterly direction and terminates near the end of Sarn Bwch. This salient correlates with the charted lobe of the 10 fathom bathymetric contour (Text-fig. 2).

Text-fig. 34 shows two clusters of distribution vectors adjacent to Sarn Badrig. Those in the vicinity of the shoaling end of Sarn Badrig are directed in a southward direction and join the mid-day salient. For deeper water, other vectors suggest the introduction of sands from beyond Sarn Badrig in that vicinity. Numerous vectors, pointing eastward, suggest that some detritus is brought into the area from beyond the western margin of the survey. A suite of vectors extending northwestward and northward from the outer reaches of Sarn Wallog defines a major mid-bay zone of sediment transport.

In the south/central part of the survey, several lines designating zones of distribution may be interpreted as transport either north or south and either east or west; it is not possible to define a preferred direction. These mid-bay " trend lines " are, however, in alignment with a known gap in Sarn Wallog. Distribution of chemical elements within and at the mouth of each of the estuaries supports the previous suggestion that estuary infilling is by sediment from the bay. No chemical vectors could be plotted for distribution seaward from the Dyfi estuary, and only one vector is charted for distribution seaward at the mouth of the Mawddach estuary.

The current-influenced accessory mineral enrichment results in proportionately higher values for several trace elements and shows that preferential enrichment takes place in the paths of strong tidal currents. Zirconium enrichment, for example, occurs in the fine sands, and since there is no concomitant increase for any gross mineralogical component, distribution vectors for those elements normally associated with accessories are hydraulically related (cf., Rittenhouse, 1943). Thus, while the composite element distribution plan, in part, reflects tidal current/mineralogical associations, it does not always signify true dispersal. In Cardigan Bay, grain dispersal and element distribution plans are obviously related, however. While the composite grain dispersal plan (Text-fig. 33) is undoubtedly the better overall indicator of sediment source and transport within the region, the element distribu-

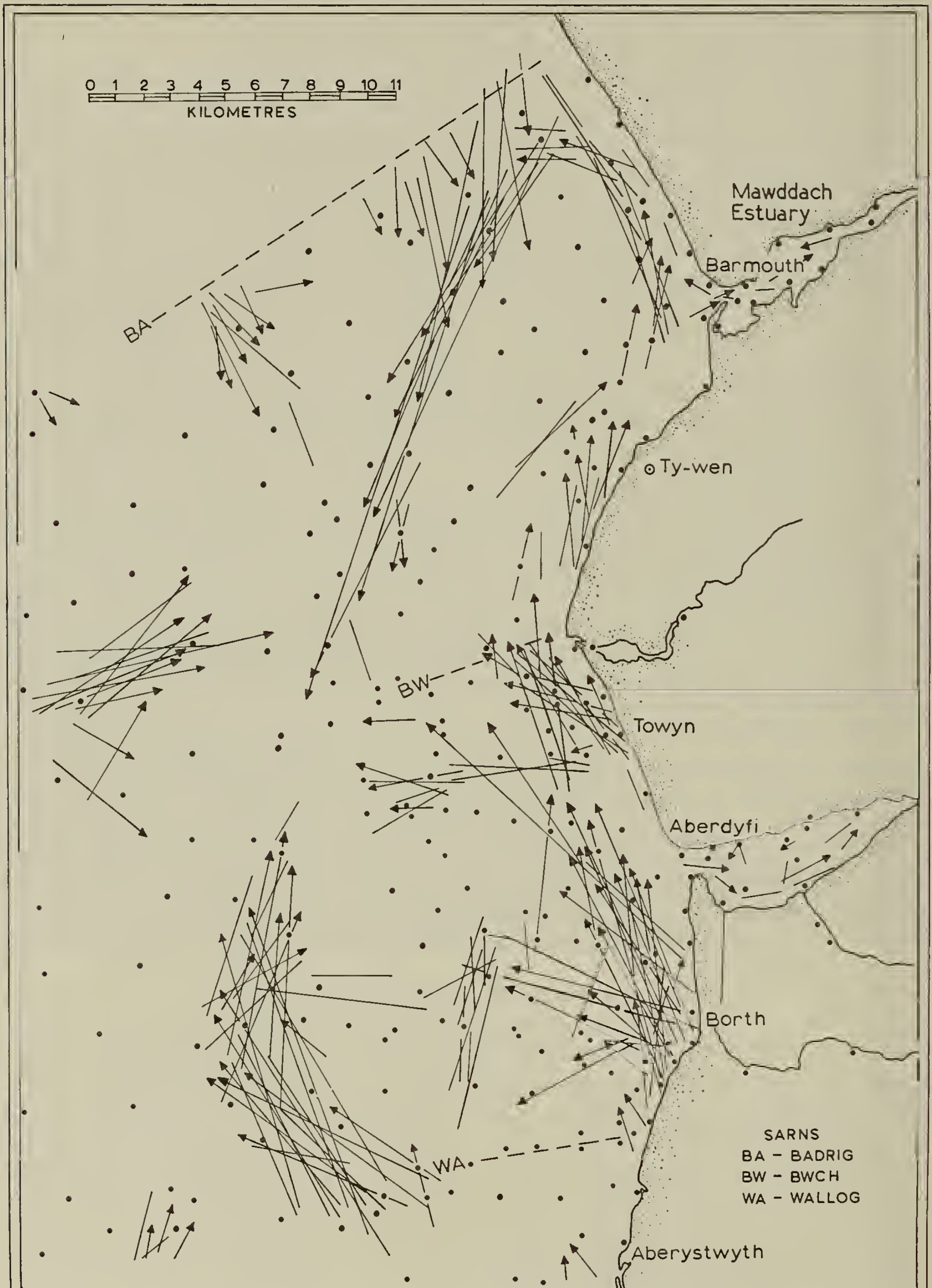

FIG. 34. Chart showing distribution vectors for the spectrographically determined chemical elements.

tion plan (Text-fig. 34) is the better indicator of direction and relative magnitude of tidal currents, although many elements are dispersal controlled.

(c) *Compositional classification of sediments*

Two schemes (van Andel, 1958 ; Pettijohn, 1949) were used to establish the compositional classification of the Cardigan Bay deposits (Text-figs. 35, 36).

Recent reviewers (Huckenholz, 1963 ; Klein, 1963) of sandstone classifications emphasize that most schemes are based on petrographically determined end-members and that one pole is generally assigned to lithic fragments, thus limiting the applicability of diffraction data, particularly where lithic fragments are abundant. On the other hand, a classification based on gross mineralogy is useful for comparing chemical data, since the distribution of elements related to gross mineralogy is meaningful only when so compared, regardless of the grain types present. The better sorted a deposit is and the more its constituent minerals are found as single grains, then the more worthwhile the gross (diffraction based) classification and the more comparable it is with a petrographically based classification. In a study concerned with establishing the petrographic nature of deposits, a genetically oriented classification (Van Andel, 1958) would suffice. However, sedimentologists need a classification based upon more rigid, quantitative, compositional limits and less subject to inherent gross variation resulting from specific or interpretive variations of the constituent grains themselves. If, for example, several hundred individual grains, all of which contained a small fragment of a phyllosilicate mineral, were counted, the sediment would be classified as a " greywacke " according to Van Andel's scheme. It is clear that the chemical and X-ray diffraction data for this sediment could not be compared with data for clay-rich greywackes. Thus, some reasonable approach must be taken in classifying unconsolidated detritus lest the resulting nomenclature be wholly unrepresentative in fact as well as in concept. Furthermore, as the use of chemical and X-ray diffraction data becomes more commonplace each year, it is imperative that a scheme based on the gross mineralogy, regardless of its petrographic distribution, should be considered. This is particularly true in comparing chemical data for the several types of deposits, for in many instances it is not feasible to subject samples to partition analysis in order to establish component limits and geochemical/mineralogical associations. Indeed, in comparing Recent with ancient sediments, gross diffraction analysis and gross spectrochemical analysis may well provide the most useful data for approaching comparative sedimentological investigations.

Text-fig. 35 shows the Cardigan Bay sediments plotted according to the van Andel (petrographic) scheme in which clay is not an end-member in spite of its geochemical and environmental importance. According to this scheme, most of the Cardigan Bay sands fall into the sub-greywacke category, with a few assigned to the greywacke category. Unfortunately, this terminology is misleading because the greywackes were derived from the Aberystwyth grits in the first place. If geochemical correlations based on the van Andel scheme were made, it would be difficult to assign proportionate values to those elements associated with matrix clays, or with combined lithic/mica grains, regardless of their textural state. The

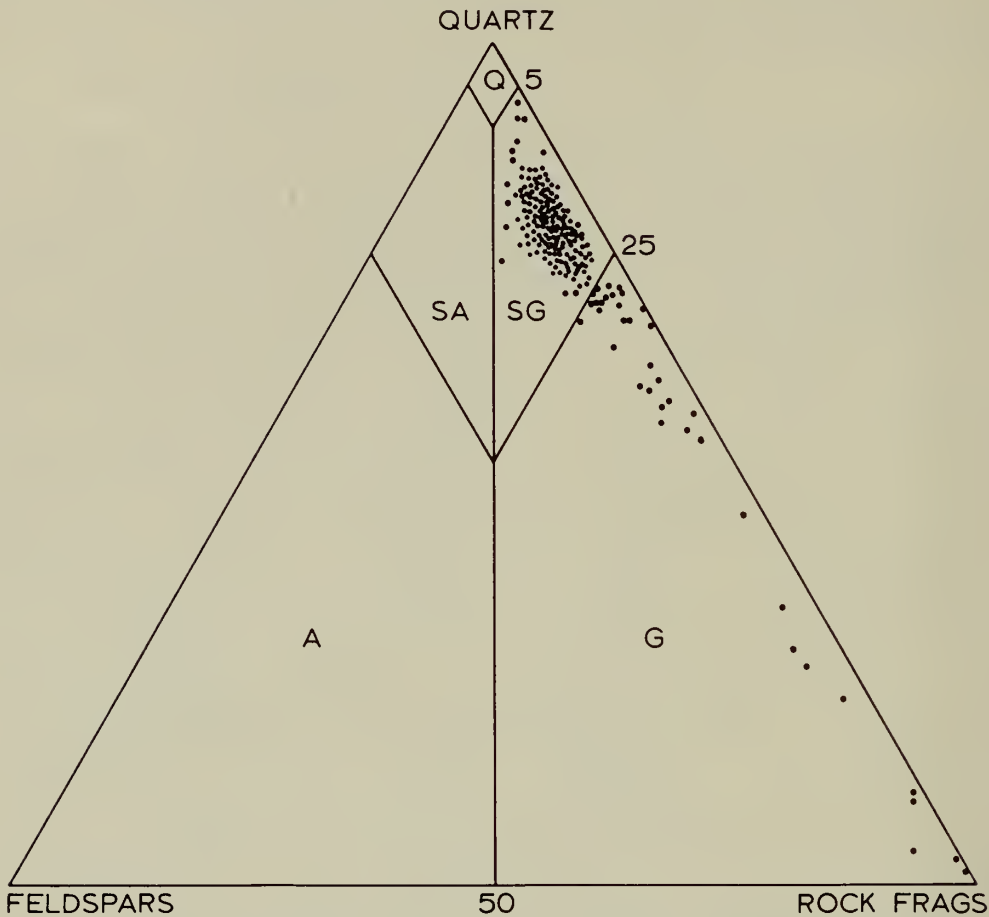

FIG. 35. Cardigan Bay sediments plotted according to the van Andel (1958) classification scheme. Note that most bay sands are classified as sub-greywackes. This scheme is based on petrographic data. Types are as follows: Q, quartzose sand ; SG, sub-greywacke ; G, greywacke ; SA, sub-arkose ; and A, arkose.

van Andel scheme does show, however, that relative to the individual feldspar grains, the effective variation is simply a changing ratio between quartz and lithic fragments.

Text-fig. 36, based on the Pettijohn system, is plotted using the end-members quartz, feldspar and clay, regardless of their texture or petrographic combinations. The reported diffraction data were used to plot each sample in this scheme, and here we see a different categorization for the majority of sediments in northern Cardigan Bay. Unlike the van Andel scheme, whereby most of the deposits are classified as sub-greywackes, the Pettijohn category in which they fall is that of quartzose sands with some few samples, about ten, classified as feldspathic sands. The interesting feature about this classification is that clay (phyllosilicates) is important, although it is completely within the lithic fragments. Moreover, this

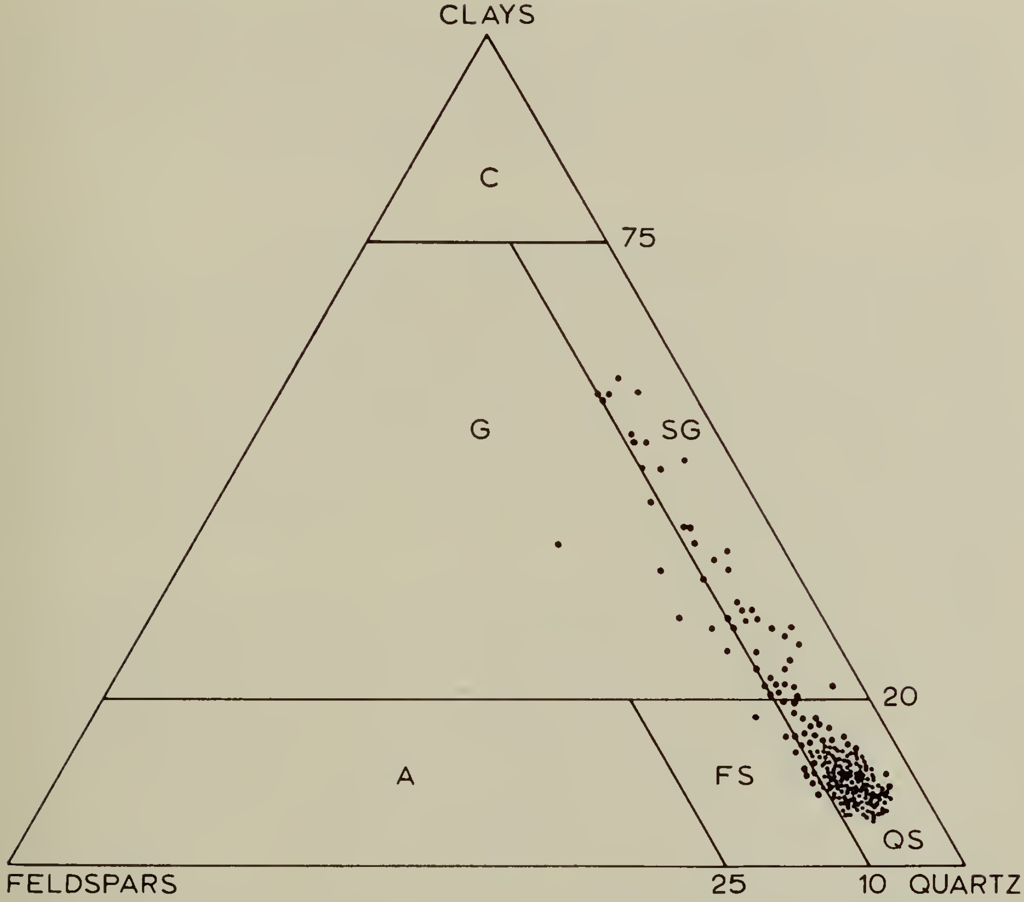

FIG. 36. Cardigan Bay sediments classified according to the basic Pettijohn (1957) scheme. Samples plotted here are based on X-ray data for end-member assignment (cf. Moore, 1963). Note that in this system most of the bay deposits are classified as quartzose sands.

scheme is ideally suited for comparing trace element data and other mineralogically related parameters, particularly when sediment terminology alone is reported, and it has been used for classifying other Recent, shallow water sediments (Moore, 1963).

A descriptive petrographic term, not necessarily an entire classification scheme, which may be used to modify the textural description, is useful, particularly for providing more complete descriptions and for signifying the abundance of lithic grains relative to quartz grains. In keeping with this need, a compositional modifier based on petrographic determinations is suggested. This is based on the ratio of quartz grains to lithic grains. A ratio of 9·0 or greater signifies quartzose ; between 9·0 and 3·0, sub-lithic ; less than 3·0, lithic. In the absence of appreciable quantities of detrital feldspar and clay, this modifier suffices to define the general petrographic/compositional character of the deposit. Used in conjunction with the textural and sorting terms, it provides a descriptive terminology readily understood by others.

In short, the van Andel scheme is recommended for any comparison based on, and limited to, petrographic variables, whereas the Pettijohn scheme is recommended for comparisons relating gross mineralogical and geochemical associations, needing a common reference of classification. By the former, most bay sands are termed " sub-greywackes " ; by the latter, " quartzose sands ".

(*d*) *Textural and mineralogical relationships*

Text-fig. 37 shows the correlation of grain size (ϕ *Mz*) with total phyllosilicates, i.e., mica and chlorite, as determined by X-ray analysis. For those samples coarser than 2 ϕ *Mz*, there is a corresponding increase in the amount of total phyllosilicates ascribed to increasing amounts of lithic fragments contained in the coarser grained deposits. Samples containing small amounts of phyllosilicates, i.e., less than 10%, are generally restricted to the size range between 1 and 3 ϕ *Mz*. The lowest phyllosilicate contents are found in sediments between about 2·0 and 2·5 ϕ *Mz*. One might deduce from this that lithic grains, in general, are removed from the fine sands by the abrasive action of transport by bottom currents, inasmuch as these same fine sands are those highest in quartz.

Folk (1961, p. 125) suggests that the mineralogy of sediments may be controlled by grain size through preferential sorting or by the composition at the source. In the present study we have found that there is an overlap of these two causal effects. In the first instance, most of the lithic fragments are similar in composition to the adjacent rocks of Wales, and thus disaggregation into various sizes does little more than effect a clastic state. Study of the data, as well as careful inspection of thin-sections, has failed to show that there is any appreciable diagenesis of the lithic fragments encountered in these bay deposits. Furthermore, little opportunity exists for deposition of fine mica and chlorite flakes after their separation by mechanical degradation of larger lithic clastics. The environmental energy regime for this area of Cardigan Bay is such that strong currents remove all sizes below the very fine grained sands and their hydraulic equivalents. It should be noted too that the diagenesis of mica and chlorite is subject to the same laws of physical chemistry as any other particulate matter, i.e., a large specific surface area is necessary to enhance the rate as well as the completeness of chemical alteration. The short length of geologic time that these phyllosilicate-bearing lithic grains have been submerged in Cardigan Bay waters and their inherently large grain size and small surface area eliminates the possibility of advanced diagenetic (chemical) alteration.

Nowhere in the reported data do values for the fine fractions suggest that phyllosilicates occur as clay size, individual mineral grains ; thus, all phyllosilicates are functionally, as well as genetically, related to lithic fragments. Indeed, for those samples having values for coarse sizes exceeding 1 ϕ *Mz*, the total phyllosilicates are always indicative of large fragments of previously existing rocks, primarily slates and arenites. Further Text-fig. 37 suggests that, for decreasing grain size below fine sands (higher positive ϕ *Mz* values), there is only a slight increase in total phyllosilicates.

Careful petrographic study of the various samples shows that the higher phyllo-

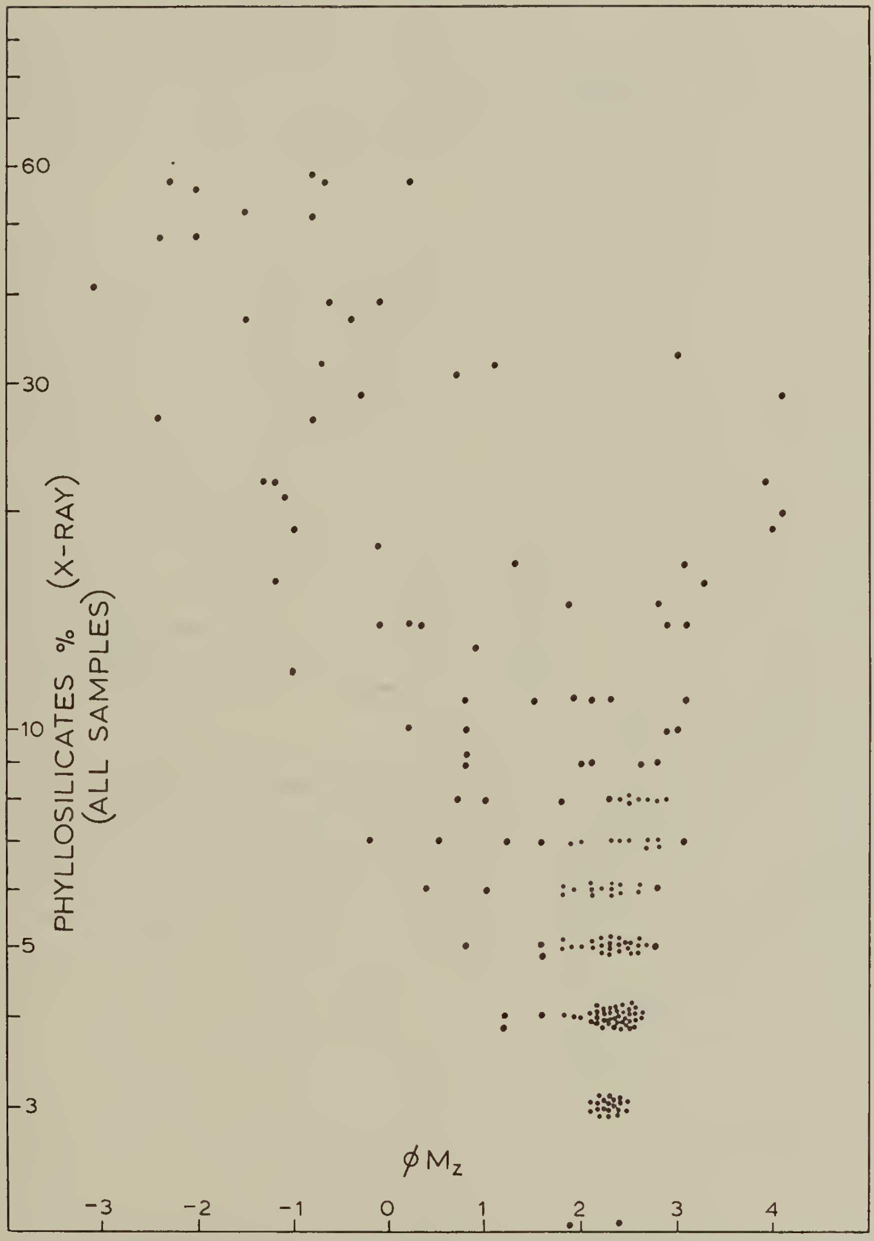

FIG. 37. Relationship between texture (ϕ *Mz*) and total phyllosilicates (10 Å muscovite and 14 Å chlorite). Note the correlation between increasing grain size and increasing mica-chlorite content, the latter being related to lithic fragments.

silicate values at marsh stations in the estuaries are related to accumulations of very small slate fragments and not to clay detritus. In fact, it is only at these few isolated estuary sites that apparent enrichment of these two clay varieties (10 Å and 14 Å) may be realistically interpreted as true deposition. The hydraulic entrapment is caused by protection of the site by *Spartina* or other marsh grass, and by locally weak tidal currents. That these estuary sites are local areas of low-energy deposition is further substantiated by the geochemical data, for instance, zirconium is not enriched there. In summary, phyllosilicates correlate with increasingly negative ϕ *Mz* values and thus with coarser texture, and only rarely with decreasing grain sizes smaller than the 3 ϕ *Mz* boundary.

Folk (1961) has pointed out that feldspar in reasonably well sorted marine sands is most abundant in the size ranges between about 2 and 3 ϕ. This textural/mineralogical relationship is also found for the Cardigan Bay sands. Inasmuch as the thin section studies show that feldspars predominantly occur as individual grains and are usually smaller than the host fraction, the use of diffraction data is instructive. A plot of ϕ *Mz* with total feldspar in sediments smaller than 1·5 ϕ shows an increase in feldspar with decreasing grain size. For the fine sands as a group the minima for feldspar (approximately 3 %) occur near the 2 ϕ *Mz* boundary (Text-fig. 38), while the maxima (in excess of 10 %) are noted for those samples near the 3 ϕ *Mz* boundary. In considering those sediments coarser than 1·5 ϕ *Mz*, there appears to be a linear increase at least through the very coarse sand ranges. Since this observation is based only on about twenty samples, it is questionable whether any definite conclusions can be reached. Moreover, feldspar in the coarser grained deposits is related, in part, at least, to feldspar within rock fragments, and small grains of feldspar result from abrasion within the environment of sedimentation and from the grain sizes which prevail at the source.

Although quartz is considered in detail elsewhere in this report, it is useful from an interpretive standpoint to consider the correlation of texture with total quartz (Text-fig. 38). This plot shows that the data maxima are largely restricted to those samples between 1·8 and 2·5 ϕ *Mz*, with the majority falling in the 2 to 2·5 ϕ *Mz* range. It is noteworthy that the coarser range of the fine sand interval is also the range for phyllosilicate minima. This means that the most mineralogically mature sands are those in the 2 to 2·5 ϕ range of the fine sand interval. With increasing grain size, there is a decrease in the amount of quartz present, i.e., for those samples exceeding -1 ϕ *Mz*, less than about 60 % quartz is reported. Such a relationship is logical in that these same coarse samples are those containing the greatest amount of lithic fragments. Furthermore, for those samples with reported values between 2·5 and 4 ϕ *Mz*, there is also a decrease in total quartz, which will be connected with an increase in feldspars and phyllosilicates. The maximum sizes of many grains are, however, controlled by their sizes in the original provenance suite. Though hydrothermal quartz veins present in the adjacent land mass could provide large quartz fragments, the data do not show that they contribute much to the bay detritus.

The several quartz maxima as determined by X-ray diffraction confirm petrographic observations, i.e., the most mineralogically mature sands are those between 2·0 and 2·5 ϕ *Mz*, i.e., largely the coarser range within the fine sand interval. While X-ray data for total quartz are useful as indicators of gross mineralogical maturity of the sediments, detailed study of quartz by petrographic methods is necessary in order to establish its nature and dispersal.

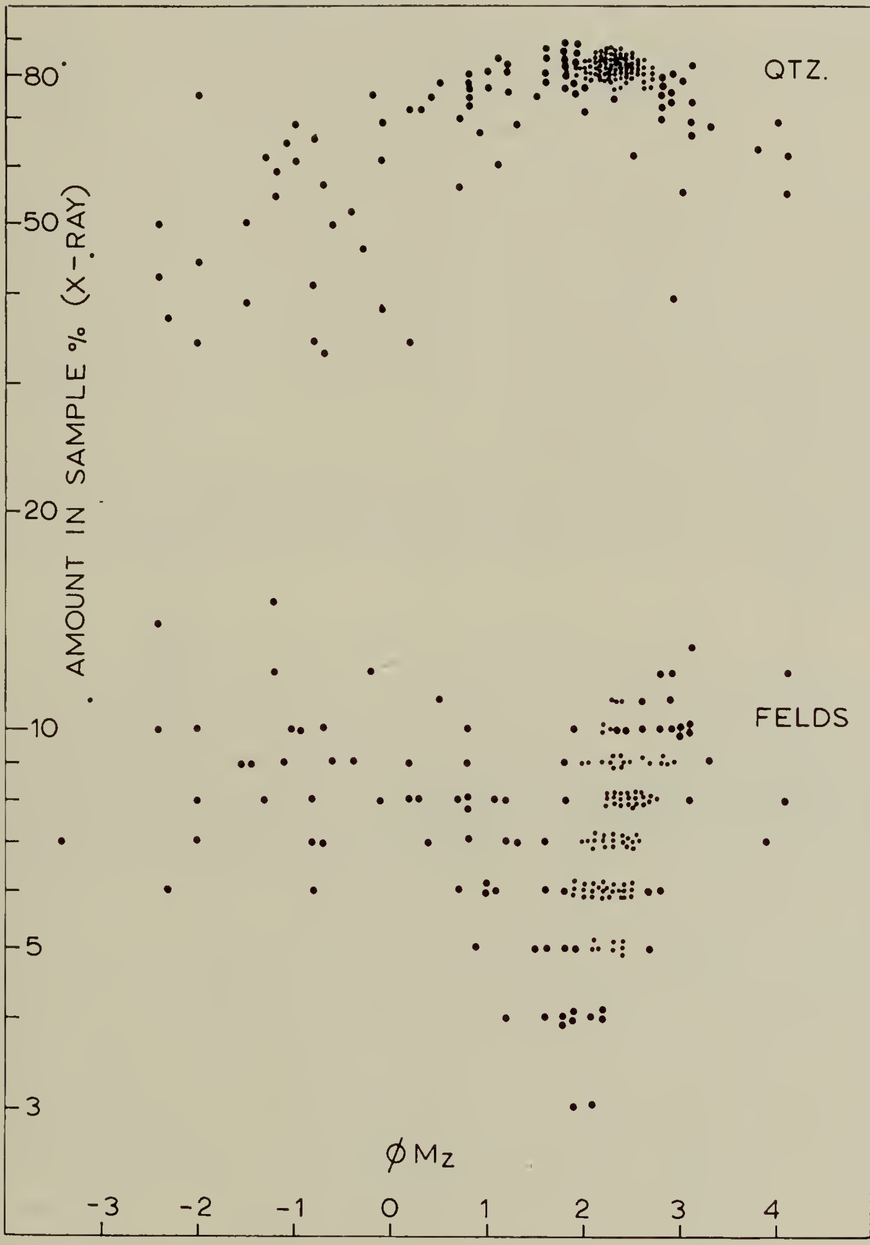

FIG. 38. Relationship between texture (ϕ Mz) and total quartz (upper plot), and between texture (ϕ Mz) and total feldspar content (lower plot). Note the definite correlation between decreasing grain size and increasing feldspar for the fine sands (2–3 ϕ Mz), and the quartz maxima associated with medium and fine sands.

(*e*) *Textural and petrographical relationships*

Inasmuch as considerable emphasis is placed on the petrographical character of the several quartz types and their dispersal within the region, it was necessary to test statistically the relationship between the several quartz varieties and the texture of the constituent deposits. In no instance was an obvious correlation between quartz type and grain size found. The importance of "randomness" between specific quartz varieties and texture cannot be over emphasized, since for the dispersal plans to be significant, there must be no correlation between quartz type and grain size. On the other hand, a correlation does exist between texture and lithic fragments for those samples with median diameters exceeding about 1 mm. As these deposits constitute a relatively small portion of the bay floor cover, this correlation is seemingly important. However, within the well sorted fine grained sand, a single Wentworth grade, no correlation exists between total lithic fragments and intra-grade textural variations.

During the course of grain counting, it was noticed that most of the orthoclase occurred as sub-rounded grains which were usually smaller in size than the host (quartz) fraction. In most samples, plagioclase grains followed this same pattern. This petrographic observation agrees with that made previously from X-ray and textural data.

(*f*) *Relationships between chemistry and texture*

For some elements, there are correlations between the texture of the Cardigan Bay sands and element abundance. Two examples of this are the correlation of zirconium and median diameter, and the correlation of titanium and median diameter. Text-fig. 39, a plot of zirconium and median diameter data, shows that zirconium enrichment is restricted entirely to the fine sands. Since the reported mineralogical data do not show proportionate phyllosilicate increases (the only other possible carrier of zirconium), the enrichment of this element results from the presence of the accessory mineral zircon. Zircon is abundant in Cardigan Bay sands.

Zirconium values generally increase with decreasing grain size, from low values of about 150 ppm for those samples with a median diameter exceeding 0·7 mm., to high values of over 3,000 ppm for certain fine sands with Md values of slightly less than 0·2 mm. (Text-fig. 39). Indeed, the rate of increase of zirconium with decreasing grain size is greatest in this fine sand range. This relationship is reasonable in light of previous research by Rittenhouse (1943), who found that zircon, because of its high specific gravity, could be present as finer grained clastics within somewhat coarser grained deposits. He found that the Md for zircon grains was about 0·07 mm. for a host fraction with an Md of about 0·18 to 0·20 mm. The present interpretation of Cardigan Bay sediments is that the zircon grains, presumably weathered from such sources as the nearby grits, are size equivalent to the host sand and, furthermore, that the differential in transport is such that the quartz grains are transported at a slightly higher rate than are zircon grains. This mechanism, which admittedly may not always be balanced, provides for net enrichment of zircon grains, i.e., the zircons accumulate as a minor lag concentrate due mainly to preferen-

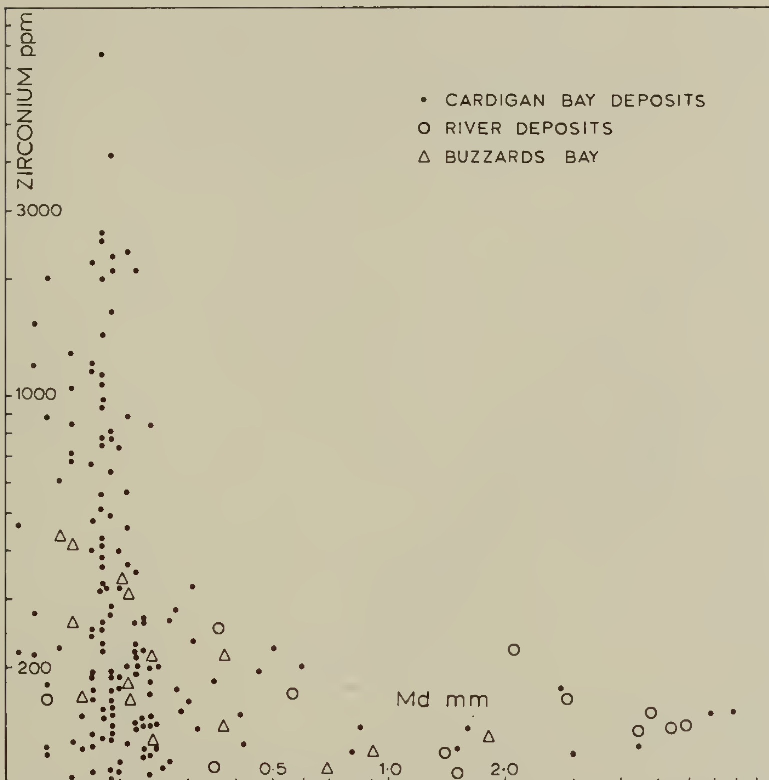

FIG. 39. Relationship between the trace element zirconium and texture (Md). Here the Cardigan Bay deposits are seen to have pronounced enrichment of Zirconium in comparison with certain other similar textured sands. Zirconium enrichment in Cardigan Bay sands is ascribed to local concentrations of zircon.

tial removal of some host constituents. Support for the foregoing interpretation is found in the work of Inman (1949), who observed that fine sand is the most easily moved of the several sand grades, and that the coarser and finer grades, being moved by surface creep, tend to lag behind. Had the enrichment of zirconium been reported for only one or two samples, the data could very well be regarded as anomalous, but with so many samples in the fine sand range with zirconium exceeding 500 ppm, they must be considered true concentrates, sedimentologically, if not economically. Furthermore, the distribution of zirconium (Text-fig. 32) shows that this element is concentrated in the paths of established grain dispersal and element distribution zones (Text-figs. 33, 34), confirming the environmental tidal energy control.

In order to compare these zirconium-rich deposits with others from a shallow water environment but of known active deposition, the author has selected data for certain other Recent sand samples of equivalent texture (Moore, 1963). These data for a low-energy environment on the Atlantic coast of America also show an increase of zirconium with decreasing grain size (Text-fig. 39), with the highest zirconium values being reported for sands of approximately 0·15 mm. Md. While sands in both areas of comparison are texturally alike, the Cardigan Bay (high energy) sands are greatly enriched in zirconium over those sands deposited in a normal (low energy) environment.

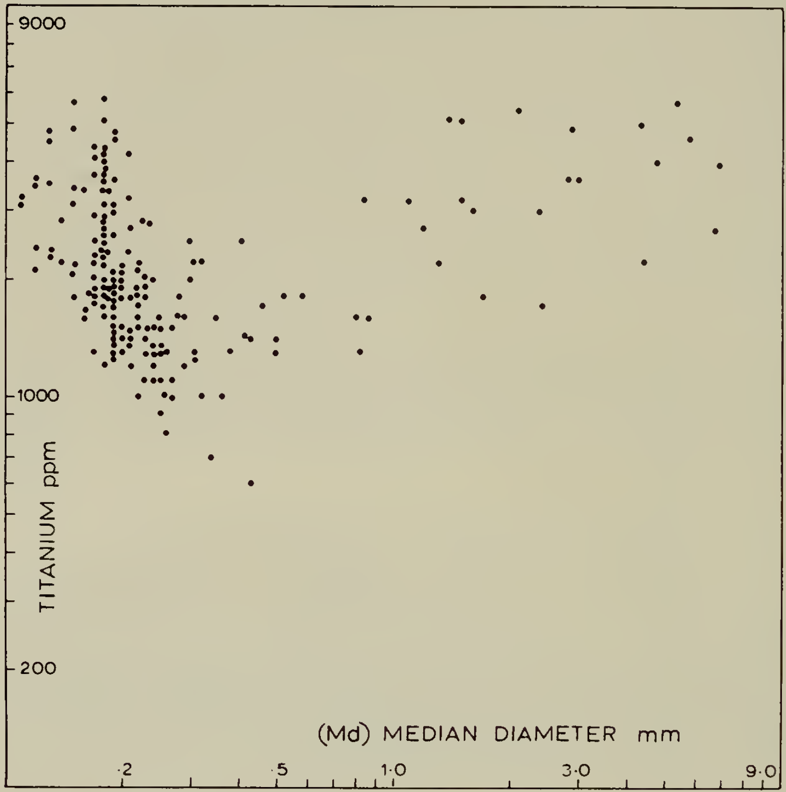

FIG. 40. Plot of titanium with median diameter for Cardigan Bay deposits. Note the increase in Ti with corresponding decrease in diameter for those sediments below 0·30 mm. Md. Ti appears to be related to one or more of the accessory minerals in the fine sands, and to lithic fragments in the coarse sands.

The foregoing interpretation is not invalidated by the work of Hirst (1962), who concluded that zirconium distribution in sediments from the Gulf of Paria is probably related to provenance rather than sorting of the sediments during transport. Gulf of Paria deposits are not similar, generally, to the Cardigan Bay sediments because the former are appreciably higher in clays, and, in fact, Hirst suggests (*op. cit.*, p. 1,182) that the trace elements and most minor elements are structurally combined within the lattices of the several clay minerals present there. Nevertheless, it is interesting to consider his Zr data; he reports an average of 436 ppm for delta sands and 413 ppm for platform sands. Neither of these values suggests that abundant zirconium is structurally combined in phyllosilicates because (*op. cit.*, p. 1,180) an average of 169 ppm is reported for the clay deposits. Furthermore,

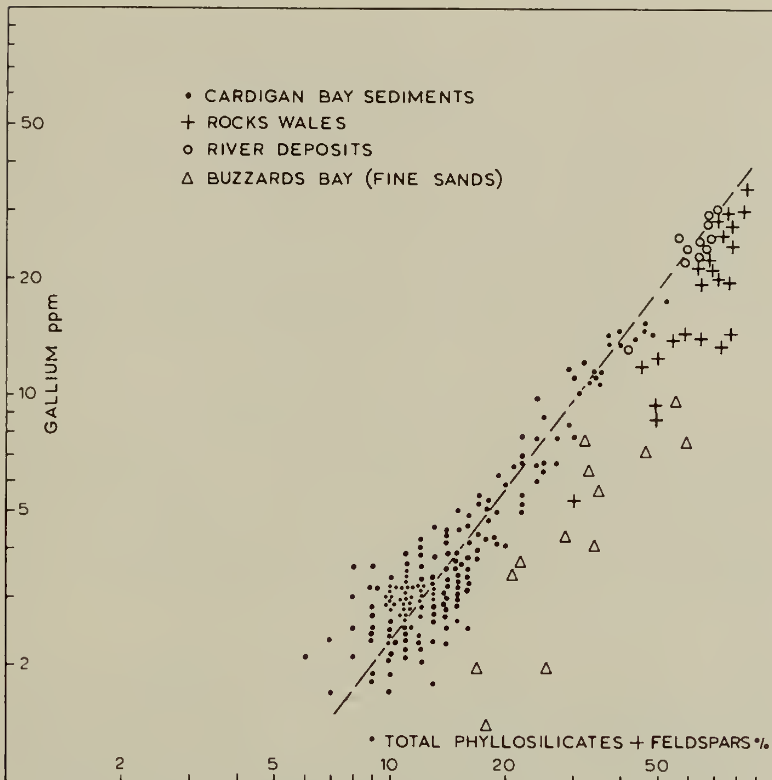

FIG. 41. Correlation of gallium with the total of phyllosilicates plus feldspars. Here the Cardigan Bay deposits and nearby river deposits show a pronounced linear relation. Comparative deposits from Buzzards Bay also show a linear relation, but deficient in gallium; variation in the 10 Å/14 Å ratio is a possible reason for the shift. Gallium replaces aluminium in both phyllosilicates and feldspars.

van Andel & Postma (1954), in the original description of the Gulf of Paria sediments, report (pp. 182–185) that zircon is the dominant heavy mineral in all the essentially arenaceous deposits; in fact, no other accessory mineral is present in quantities exceeding that of zircon.

The present study suggests that spectrochemical data may provide a useful indicator of the environment. The writer suggests that for normal, low-energy deposition within a basin or on an open shelf, the rate of increase of zirconium with the concomitant decrease in grain size is a gradual one, and that the range of average values for zirconium in well sorted sands is probably of the order of 200 to 500 ppm. This agrees with Pettijohn (1963, p. 11), who gives an approximate average range of 200–250 ppm. However, in the case of mobile sands, a very sharp rate of increase in the zirconium content with decrease in grain size below about 0·30 mm. Md is significant evidence of preferential sorting by high energy tidal currents and, as such, implies considerable transport. This interpretation does not rule out net deposition for mobile, high-zirconium sands, but rather it provides a sound basis for recognizing their relationship to a high-energy environment.

A similar relationship exists between titanium and median diameter (Text-fig. 40). In this plot titanium increases both with decreasing grain size below about 0·3 mm. Md and with increasing grain size above about this median diameter. The correlation between increasing titanium and decreasing Md is a readily understood one in that titanium is geochemically associated with two common accessory minerals, rutile and ilmenite, in sand. However, the increase of titanium with increasing grain size demands a different interpretation. It is possible that some titanium is combined within the lattices of phyllosilicate minerals which are known to be constituents of the lithic fragments in these coarser grained sediments. In the present discussion, the main interest is in the inverse regression between titanium and texture for the fine sands in Cardigan Bay. Whether titanium is geochemically associated with ilmenite or rutile, or both in these sands, is not an important point in itself, but rather that it is associated with the heavy mineral suite. Thus, the reported titanium values for Cardigan Bay sediments confirm the zirconium/Md relationship, i.e., some elements are enriched in the fine sands and their mineralogical hosts are the heavy minerals. Moreover, the relationships are sensitive to the physical energy environment, and thus may be used to interpret ancient sediments.

(g) *Trace elements and gross mineralogy*

Some trace elements in the Cardigan Bay deposits are related to gross mineralogical constituents. An example of this relationship is expressed in Text-fig. 41, a correlation plot of the element gallium with the total of combined phyllosilicates and feldspars. Although these two mineral groups are in the minority for the bay sediments, they are geochemically important as hosts for several trace elements. Gallium data show a positive, linear relationship to the sum of phyllosilicate and feldspar data percentages. The several gallium minima, i.e., values below about 5 ppm, show a slight spread, but the linear relationship is observable. For gallium values above about 5 ppm, the relationship is a pronounced one. Sediments with gallium in amounts above 10 ppm also contain numerous rock fragments, and of course, their phyllosilicates and feldspars. In fact, the distribution of gallium provides important evidence of affinity with the phyllosilicates and feldspars rather than with the accessory minerals. For instance, Station 240 with 5·2 ppm gallium shows a total phyllosilicate/feldspar value of 13%. On the other hand, the zirconium content for Station 240 exceeds 10,000 ppm, and titanium at Station 240 is reported in excess of 20,000 ppm. These two data suggest an abundance of heavy minerals, yet gallium remains low. Data for the reference rocks collected in central and north Wales show a like linear relationship for this element and its mineralogical associations although several data indicate less gallium. The stream deposits plot on the same trend as for the bay samples. This is a reflection of provenance.

Also plotted are selected data for Recent sediments of similar mineralogy and texture from Buzzards Bay on the Atlantic coast of North America. These data likewise show a linear distribution, but for the same amount of phyllosilicates and feldspars, contain less gallium than the Cardigan Bay deposits. Since phyllosilicates and feldspars are minerals rich in aluminium, the correlation of gallium with phyllosilicates and feldspars is a reasonable one because of the diadochy between the trivalent ions Ga^{+++} and Al^{+++} (Rankama & Sahama, 1950, p. 720).

Hirst (1962), in his geochemical study of the Gulf of Paria sediments, suggested that gallium as well as chromium, vanadium, copper, lead and barium, and, to a lesser extent, cobalt, nickel and boron were brought to the basin of deposition structurally combined in the lattices of clay minerals. Certainly, in the case of Ga, his findings provide valuable insight into gallium-sediment geochemistry. Similarly, Borisenok & Saukov (1960) in their study of the geochemical cycle of gallium report that it is chiefly governed by its relationship with aluminium.

(*h*) *Element-to-element relationships*

Plots of element pairs are instructive and provide additional means for characterizing groups of sediments, for establishing element associations in nature, and for reaching a better understanding of environmental influences. Of the numerous possible combinations, five examples have been selected : titanium/iron ; calcium/strontium ; zirconium/titanium ; scandium/gallium ; and cobalt/nickel.

Titanium/Iron. A plot of Ti and Fe_2O_3 data (Text-fig. 42) shows that a good linear relationship exists between these two elements. For the fine sands (2–3 ϕ Mz) in these deposits the Fe_2O_3 content varies between 1·5 and 3%, whilst Ti varies between 1,000 and 5,000 ppm. In addition, the Ti/Fe_2O_3 values show that for a small increase in Fe_2O_3 there is a relatively large increase in the amount of titanium present. The titanium in these sands is doubtless associated with accessory ilmenite and rutile. This sharply defined linear regression represents high energy sands which are well sorted, relatively mobile, and with only a small amount of phyllosilicate minerals present. For comparison, sands of similar texture and mineralogy from Buzzards Bay (a low energy environment) have been plotted. These sands show somewhat less iron, but equivalently higher titanium values, and although they plot in a linear pattern, it has a different slope. For further comparison, the data for the reference rocks from Wales are also presented. For these, there is a less definite linearity to their plot, but they do contain almost twice as much iron as some of the fine sands in the bay and yet contain no more titanium. Whether the additional iron in the lithic samples is due to sulphides, or to iron-rich 14 Å phyllosilicates is not known, but the latter is suspected.

In short, the steep regression for Ti and Fe_2O_3 characterizes high energy sands.

Calcium/Strontium. The second example of element-to-element relationships is that between calcium and strontium ; a relationship between a minor element (Ca) and a trace element (Sr) and one of environmental significance. It has been reported by Turekian & Kulp (1956) that strontium is present within calcite and aragonite shells. Strontium, of course, may be, and usually is, a constituent trace element of fossils and of sedimentary rocks in general. However, bioclastic fragments provide, by far, the major amount of calcium carbonate in the Cardigan Bay deposits, even though small grains of dolomite, usually sub-rounded euhedra, do occur in

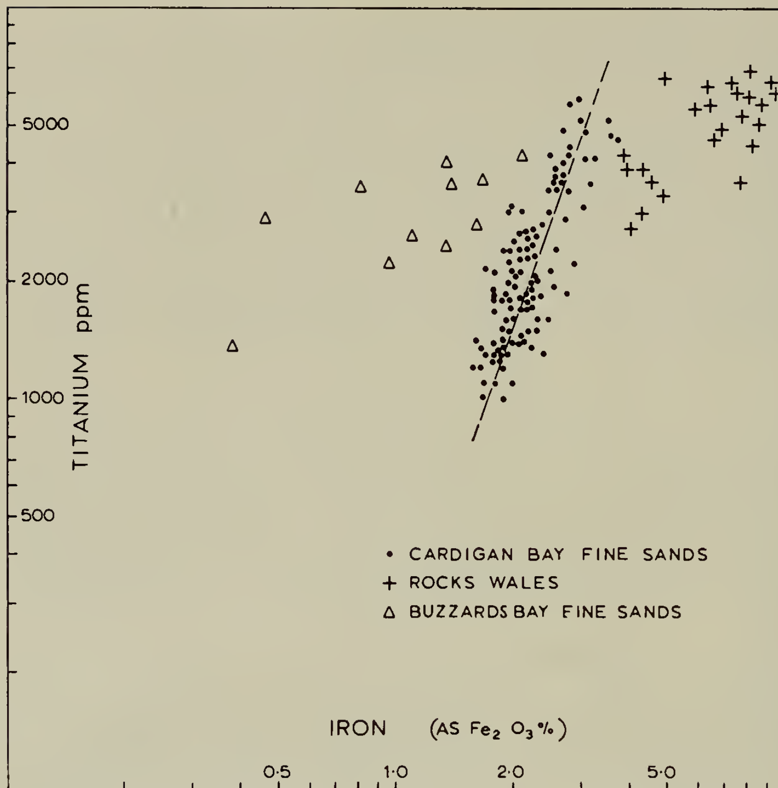

FIG. 42. Plot of titanium with iron based on spectrochemically derived data. Note the steep regression slope for the Cardigan Bay fine sands (high energy environment) in comparison with the reduced slope for similar textured sands from a low energy environment.

some of the fine grained sands. This minor mineral is reported by X-ray diffraction analysis in quantities of about 1% or less. Neglecting this small contribution of dolomite, shell fragments constitute the major source for reported calcium. Calcium and strontium are two elements which are added to the bottom sediments largely by bioclastic material at the site of deposition. It is, however, significant that strontium, although present, shows very little variation in samples (mainly freshwater) with a calcium content 1·5%. In these samples it is likely that the strontium content is related to the phyllosilicates.

In seeking a comparison with other fine grained sand deposited in a shallow water marine environment, data for selected sediments of equivalent texture have been plotted (Text-fig. 43). Although only nineteen in number, these data do show positive, correlative increases of strontium with increases in calcium below 1·5%, as well as for two stations exceeding 2·5%. In these sediments (all marine), even the lower calcium and strontium values are related and increase together.

In summary, strontium is increased only for those sediments from the Cardigan

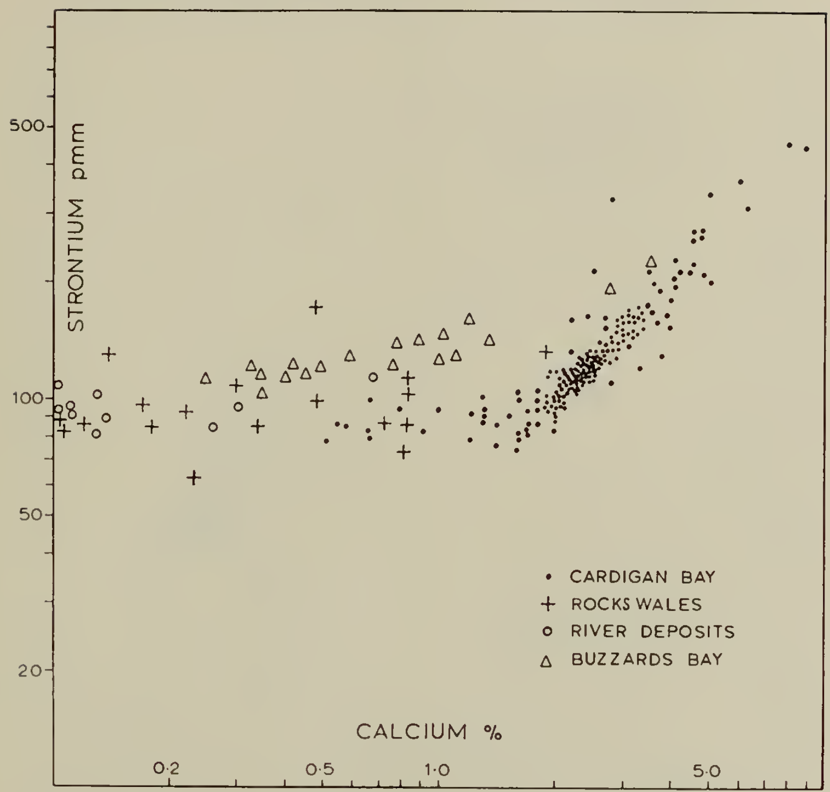

FIG. 43. Relationship between calcium and strontium. Both elements are enriched in Cardigan Bay sediments due to the presence of bioclastics. Note the steep regression for Cardigan Bay deposits (high energy environment) in comparison with the relatively reduced slope for fine grained sands from a low energy environment. Calcium and strontium have similar ionic radii, 0·99 and 1·12 respectively. Petrographic evidence further suggests that calcium and strontium are two elements largely added in the environment of sedimentation.

Bay area which contain bioclastic debris, and as such is indicative of the marine environment.

Zirconium/Titanium. The ratio between zirconium and titanium is another example of an element pair with good correlation. Here again, the bay data are representative of a high energy environment (Text-fig. 44). Both of these elements are, for these shallow bay sands, related to accessory minerals (zircon, ilmenite and rutile). Moreover, the spread of titanium data between 1,000 ppm and 5,000 ppm is such that an alternative relationship with phyllosilicates is unlikely. In comparing the Cardigan Bay data with those from Buzzards Bay, a low energy site, the latter possess less zirconium for the same relative Ti concentration, and they plot with a lesser gradient. In short, the Cardigan Bay data exhibit a sharp Ti/Zr regression when plotted, which serves to characterize them as high energy sands. An inverse relation exists for many low energy deposits.

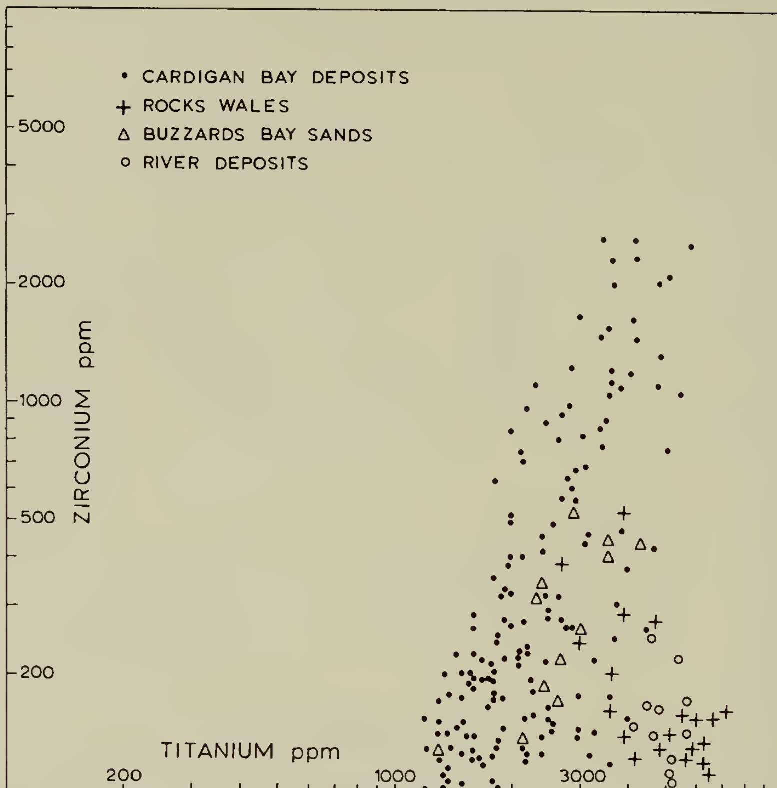

FIG. 44. Correlation between zirconium and titanium for Cardigan Bay deposits and other comparative samples. Note the steep, positive regression for the Recent sediments, with proportionately more zirconium in the high energy deposits. River samples and reference rocks, both lithic in composition, however, show an inverse relationship between zirconium and titanium. It is suggested that titanium in these is related to more than one host, probably phyllosilicates and accessories.

Scandium/Gallium. An example of correlation between two trace elements related primarily to alumino-silicates is that of scandium and gallium (Text-fig. 45). It has already been shown (Text-fig. 41) that gallium is correlative with the total amount of phyllosilicates and feldspars present in a deposit. Scandium is similarly related. Regardless of grain size or sorting of the sediment, a positive relationship exists between scandium and gallium, and ratios of these two elements are controlled by inherited mineralogy of the clastic fragments and ultimately the source rocks. Inasmuch as data for reference samples of Welsh rocks plot on the same linear trend, one may assume that a genetic relationship exists between the rocks and the bay sediments.

Similar textured marine sands from Buzzards Bay, Massachusetts, also plot with a linear Sc/Ga correlation, but they contain less scandium than the Cardigan Bay sands. Study of the data suggests that variations in provenance mineralogy, specifically the 10 Å/14 Å clay ratio is the explanation. High scandium values are

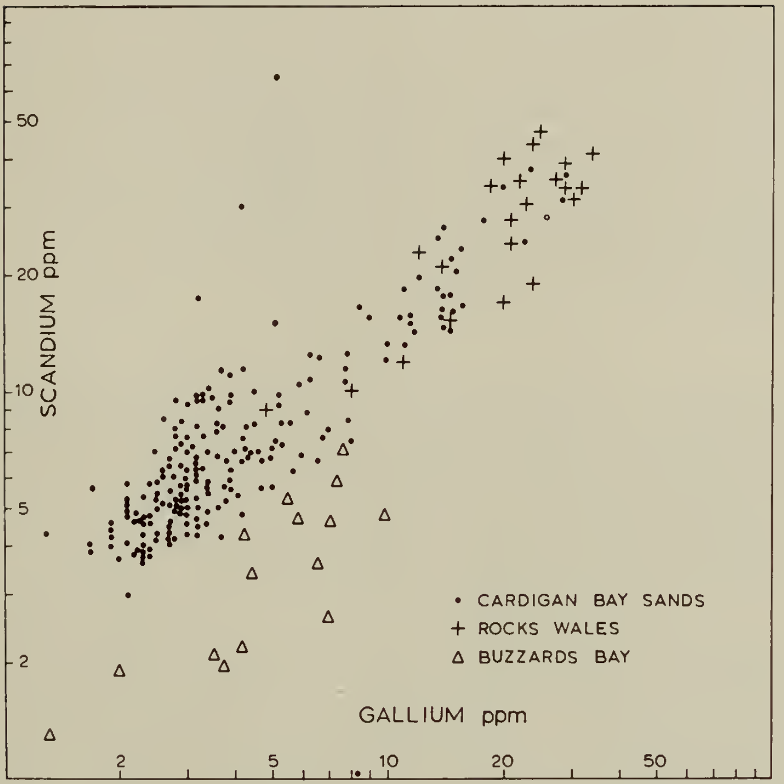

FIG. 45. An example of the correlation of a trace element pair for Cardigan Bay deposits, reference rocks from Wales, and Buzzards Bay sediments. Both the Cardigan Bay sands and the Welsh rocks plot on the same line. The linear, but steep, regression for sediments from Buzzards Bay is thought to reflect variations in the 10 Å/14 Å or other mineral ratios. In a few Cardigan Bay samples, scandium may be related to accessory minerals, but the majority of scandium and gallium are related to aluminium bearing silicates.

reported for three Cardigan Bay samples with gallium values less than 5 ppm, and these may be due to the presence of allanite, a mineral known to be present in the nearby Welsh rocks (Bromley, 1964).

Cobalt/Nickel. Cardigan Bay sediments have a Co/Ni ratio of about 0·38 (graphic determination), and reference rocks from North Wales, reported as a part of this study, have a Co/Ni ratio of about 0·42, which closely agrees with the Co/Ni ratio of 0·40 for a suite of shales from the Harlech Dome area nearby (Mohr, 1959). Hirst (1962, p. 1163) reports Co/Ni ratios for several groups of sediments from the Gulf of Paria which are in agreement with those above, e.g., 0·34 for delta sands, 0·49 for platform sands, 0·39 for green muds, 0·42 for clays and 0·34 for delta clays. Hirst (*op. cit.*, p. 1163) also pointed out that the mean ratio, about 0·40, represents the near maximum for lattice combined Co and Ni in sediments. The present study with ratios very near to 0·40 is in agreement with the findings of Hirst and others.

In fact, Co/Ni ratios between 0·35 and 0·45 are considered, generally, as good indicators of marine sediments.

Provided that trace elements are not lost during metamorphism (Turekian & Wedepohl, 1961, p. 177), element ratios may be useful for establishing the original rock type, and perhaps environment, of meta-sediments. The common repetition of certain element-to-element ratios, such as Co/Ni and others previously referred to, enhances the geochemical approach to the study of metamorphic rocks and their genesis, but such an approach requires a firm understanding of the distribution of critical chemical elements in modern sediments.

(*i*) *Some general geochemical relationships*

Numerous unfigured scatter diagrams (Krumbein & Pettijohn, 1938, p. 199) were plotted for this study using the reported data. These plots in conjunction with the findings of Weber & Middleton (1961), MacPherson (1958), Moore (1963), and Potter *et al.* (1963) provide a basis for certain of the following interpretations.

Boron. The chemical association of boron is such that it is found in two host minerals, namely, tourmaline, which has been observed in thin sections (e.g., B.M. 1964, 99 ; 127 ; and 174), and muscovite. For the latter some boron replaces potassium in the 10 Å mica lattice, but it is doubtful that it is here an indicator of salinity as suggested by Walker & Price (1963). Since the phyllosilicates in Cardigan Bay sands are not detrital clays, it is unlikely that detailed boron/potassium studies would yield accurate indices of salinity. This assumes, of course, the use of the reported data for the whole sample. It is doubtful that the lithic fragments have reached chemical equilibrium with Cardigan Bay water. In their study of lithified sediments, Weber & Middleton (1961, p. 249) report some values exceeding 100 ppm for boron. In their case, however, detrital clays were present in the samples. Pettijohn (1963, p. 12) has pointed out that boron is seldom determined for sandstones, but that a reasonable estimate would be 25–35 ppm for the " average " sandstone, which roughly corresponds to the amount found in the present survey. However, in dispersal zones (Text-fig. 25), boron values exceed 40 ppm, as the result of lag tourmaline in a high energy zone. Regardless of whether boron travels with an accessory mineral or with micas bound in lithic fragments, its preferential distribution is an important clue to sediment dispersal and to zones of sediment transport.

Barium. In Cardigan Bay sands, barium is related to the phyllosilicates, to feldspars, and in some samples to accessory minerals. The small amount of feldspar present does not provide a wide enough spread to establish conclusively how much barium is in the feldspars. Weber & Middleton (1961, p. 249) and Moore (1963, p. 541) have reported, however, that barium is related to feldspar. Weber & Middleton (*op. cit.*, p. 249) also point out that some barium is present in carbonate mineral fragments. In the present study, this does not appear to be a general trend, since for several samples with large amounts of bioclastic debris and with relatively high barium values, there are, also, abundant lithic fragments present.

Cobalt. The geochemical associations of cobalt are complex ones and its distribution in nature has not yet been fully explained (Carr & Turekian, 1961). In Cardigan Bay, cobalt distribution is related to both phyllosilicate and accessory minerals, but in the absence of partition analysis, we cannot establish the proportionate amount in each. However, it appears that " background " cobalt is related to the magnesium-bearing minerals, primarily chlorite, but that certain anomalous cobalt values, e.g., Station 240 with 135 ppm Co, are related solely to accessory mineral enrichment. Similar findings have been made by Weber & Middleton (1961), including a pyrite/cobalt relationship. It is unlikely that pyrite is present in Cardigan Bay sands, except as trace amounts in lithic fragments. Nevertheless, it would be difficult to differentiate cobalt/sulphide from cobalt/phyllosilicate relationships in lithic fragments using the reported data.

An interesting aspect of cobalt is that it is reported not to change with variation in the metamorphic grade of regionally metamorphosed sedimentary rocks (Shaw, 1954). If this is correct and if sedimentologists can obtain sufficient quantities of cobalt data on Recent sediments, one may speculate that the original environment of metamorphosed sediments might some day be determined with reasonable accuracy. Similarly, the use of this element in combination with another of equal geochemical " constancy ", e.g., nickel, may provide a useful geochemical tool for stratigraphic correlation.

Chromium. Reference to Text-fig. 26 shows that chromium, like zirconium, is distributed in zones where bottom currents are most active and that chromium is largely enriched by accessory mineral concentration. A similar finding has been made by Weber & Middleton (1961, p. 250) who consider that ilmenite and magnetite contain most of this element. They do, however, suggest that clays carry some chromium. While the Cardigan Bay samples are relatively depleted in phyllosilicates, the data suggest that a small amount of chromium is carried in that fraction. Moore (1963) found that the amount of chromium in argillaceous sediments was a good indicator of clay content, and while this observation is valid for low energy deposits, it does not provide a similar index for well sorted high energy sands. Chromium, in the latter, is concentrated in the accessory fraction and more directly reflects prominent zones of sediment transport. Hirst (1962, pp. 1158–1161) in his study of Gulf of Paria sediments found that Cr/Al and Cr/Fe ratios were moderately constant throughout the basin, and suggested that chromium is associated primarily with illite. For low energy argillaceous deposits like those in the Gulf of Paria (Hirst, 1962) and Buzzards Bay, Massachusetts (Moore, 1963), chromium is undoubtedly distributed with the clay fraction, but, in the present study area, chromium is primarily related to accessory minerals.

Copper. The geochemical association of copper in Cardigan Bay deposits is a complex one, and it appears that copper is related to phyllosilicates, accessory minerals, even some sulphides in lithic fragments and in rare quartz grains. Weber & Middleton (1961, p. 250) observed that copper varied in its geochemical associations, and they, too, found it difficult to assign a single host. Hirst (1962, p. 1167) suggests illite (equivalent to our 10 Å muscovite) as the probable mineral carrier.

Iron. From a study of the data, it is concluded that iron in Cardigan Bay sediments is primarily related to the accessory mineral suite. Some iron is contained in the mineral chlorite, but since this mineral is found in such small amounts, its iron contribution is negligible.

Magnesium. Magnesium is concentrated in the phyllosilicate suite. Similar findings by Weber & Middleton (1961, p. 250) and by Moore (1963, p. 548) confirm the magnesium-clay relationship. It is suggested that magnesium is most abundant in the 14 Å chlorite fraction.

Manganese. It is evident from the reported data as well as Text-fig. 28 that manganese is highly enriched in these shallow water marine sands. Such enrichment is uncommon, for even where clays are abundant (Moore, 1963, p. 548 ; MacPherson, 1958, p. 78 ; Goldberg & Arrhenius, 1958, p. 170), the deposits are not as rich in manganese (proportionate to the clay content) as are the Cardigan Bay sands. The anomalously high values for this trace element appear to be related in some way to the nearby rocks (Mohr, 1959), where rich manganese shales are exposed, particularly in the Harlech dome area. Thus, manganese in these sands is related both to lithic fragments and to accessory minerals, possibly including garnet. Weber & Middleton (1961, p. 250) reported that, for rocks, some manganese is associated with the carbonate fraction and some with heavy minerals. It is doubtful whether any manganese is related to carbonate minerals in the Cardigan Bay deposits, for when it is, the bioclastic debris is usually stained light brown ; a feature not observed during sample study. Staining on shells from Tremadoc Bay has been observed, and in this area a partial Mn/carbonate association may exist. Rao (1962) in a study of manganese distribution in Recent sediments off the coast of India found that manganese was concentrated in the shallow inshore sediments, and that its highest concentrations were in silty clays. Furthermore, he found an antipathetic relationship between manganese and calcium carbonate.

Nickel. Nickel is related to the accessories and the phyllosilicates. In the case of certain samples, such as for St. 240 (145 ppm) and 67 (135 ppm), the high nickel content is undoubtedly related to accessory minerals; however, for most other enrichment zones, nickel is related to lithic fragments in the sediments. In either case, it is a good indicator of sediment dispersal. The constancy of the Co/Ni ratio for marine sediments, in general, has been previously discussed.

Lead. Lead in Cardigan Bay sediments is primarily related to the phyllosilicates bound within lithic fragments, but for the area near Borth some lead may be related to detrital fragments of vein quartz. The major dispersal of lead-bearing sediments (Text-fig. 30) away from the Borth area was studied in detail, and a small amount of lead is present which cannot be accounted for by the reported diffraction data, or by the textural data (relative to the accessory/texture relationship). The only conclusive evidence would be that obtained by electron probe analysis. Lead, incidentally, is enriched in marsh sediments, but depleted in littoral sands. Turekian & Wedepohl (1961) gave 7 ppm as the average lead value for sandstones. The present data for Cardigan Bay, considering the relative mineralogy, suggest that the lead content of these sands is slightly higher than their reported average. Some clue to this enrichment may be found in the fact that the adjacent mid-Wales region was once an active lead mining area. It must be emphasized, however, that " contamination lead " is not being delivered to the bay. This may be verified by reference to the data for river samples. Hirst (1962, p. 1,168) reports lead values of 13 ppm and 17 ppm as averages for the Gulf of Paria delta and platform sands. His averages are in agreement with the present study for most of the fine sands in Cardigan Bay.

Scandium. This element, like gallium, is related to the feldspars and phyllosilicates where it replaces aluminium in the crystal lattice. It can be used, rewardingly, in provenance studies.

Strontium. By far the greatest amount of strontium is concentrated with calcium in calcite which forms the shell material of marine invertebrates. Some strontium is present in river samples and outcrop samples which do not contain bioclastic calcite. Nevertheless, strontium is still related to calcium, geochemically, even though the host may be a phyllosilicate. Excepting where calcite values are particularly high, strontium values remain fairly constant for the inshore fine grained sands with values between 100 and 150 ppm. Strontium is low in littoral and river deposits.

Vanadium. Vanadium plotted with iron shows a positive correlation. Inasmuch as most iron in Cardigan Bay sediments is contained in accessory minerals and chlorite, we may assume that vanadium follows a similar geochemical pattern in its distribution. Coarse lithic fragments cause anomalous variations at several stations with poor sorting.

(*j*) *Comments on economic applications*

The correlation of known, or potential reservoir sands, is a formidable problem in many oil producing provinces, particularly where faulted sections prohibit " straight line " correlation, and where the use of electrical resistivity and radiometric logging techniques do not differentiate to an adequate degree. It is possible that local correlation, e.g., across faults, may be established by the use of the grain classification technique, as presented in this study. Conventional, indeed even sidewall cores, would be of sufficient size to provide adequate sample material for such thin-section analysis. The obvious problem, of course, in a new oil development programme is that not enough bore holes may have been drilled to provide a coverage equivalent to the present sample distribution plan. By plotting one quartz variety against another, one could identify beds and, thus, establish local correlations on the basis of scatter diagrams alone. Caution must be exercised in attempting more than local correlation. On the other hand, the " quartz approach " applied to even a large area is rewarding in provenance study and environmental reconstruction.

It must be recognized that textural and geochemical correlations (e.g., trace element ratios) across wide areas may be more reliable than correlations based solely on petrographic types, particularly where sample distribution is limited.

Nevertheless, in subsurface rocks which have been subjected to considerable faulting, or which have limited sand facies development, the petrographic approach should prove useful. Correlation by geochemical means, particularly the use of trace-element ratios may prove worthwhile in certain circumstances where the mineralogical content is known. It is suggested that cobalt, gallium, nickel and copper would prove suitable elements for undertaking geochemical correlation of arenaceous strata. The data should be used to establish ratios for comparison, rather than to attempt correlations based solely on element abundances. For those interested in locating strand lines, or recognizing translittoral sands, such variables as calcium, strontium and barium and certain of the quartz varieties, should prove particularly rewarding in environmental-depositional reconstruction. Careful study of the reported data will suggest several additional clues for stratigraphic application. While correlation has been considered in terms of petroleum geology, it is not restricted to such an economic stratigraphic application, for " The basic principles underlying the technique of differentiating or correlating strata by means of their stable mineral components are essentially those fundamental to the science of geology " (Milner, 1962, vol. II, p. 372).

Another problem in petroleum exploration is the recognition of a potential reservoir sand. The two most important characteristics are that the sand should be reasonably fine grained and well sorted. Such aspects as trace chemistry, mineralogy and other purely compositional properties are subordinate to the basic textural requirements of a sand network and good sorting. The importance of sorting is that the interstices should not be filled with finer grained detritus even if it occurs in small volume, in order to develop the necessary porosity and permeability. Cardigan Bay sands possess the textural attributes of a good reservoir sand. In order to display the overall textural properties of size and sorting, frequency histograms of the majority of the Cardigan Bay deposits have been plotted (Text-figs. 46, 47). In Text-fig. 46, the ϕ *Mz* values for all samples between 3·5 and —1·5 are plotted in the form of a simple histogram. Clearly, the vast majority of the samples are fine sands. Inasmuch as the sample network is representative, this figure shows at a glance, the sandy nature of the bay floor. The second and, perhaps, more important quality, is that of good sorting or dispersion. Reference to Text-fig. 47 shows that the Cardigan Bay sands are well sorted with the majority being within 1·10 So and 1·30 So. Although the influence of secondary interstitial cementation and packing fabric cannot be predicted, the two prime requisites of uniform fine sand and good sorting are recognized for Cardigan Bay. While it is not within the scope of this study to discuss oil field reservoir lithologies, their recognition and correlation, the results of this study do provide additional criteria for application by exploration geologists.

Potter and Pettijohn (1963, pp. 14–15), in discussing the facies model state that " . . . *a clastic dispersal system produces attribute, scalar and directional properties forming an interrelated set* that can be used to reconstruct the original conditions of sedimentation. With adequate data and an understanding of the principles involved, one should be able to make more successful predictions of sedimentary trends." Certainly in the process of exploring for oil and gas, the competitive advantage is

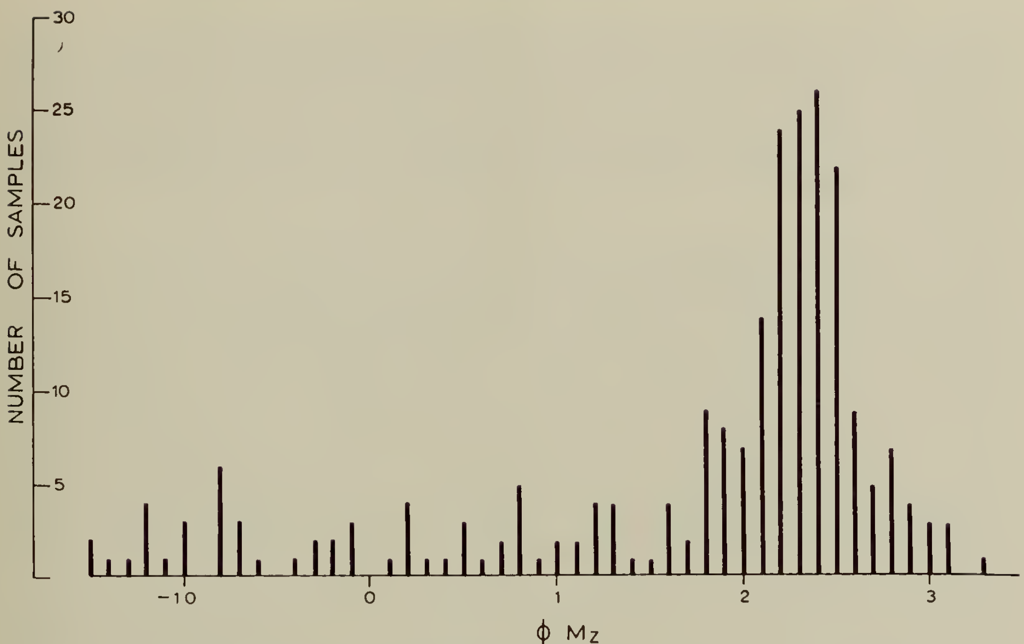

FIG. 46. Histogram of grain size values, Cardigan Bay sediments. The majority of the samples are in the sand range, a desirable textural attribute of reservoir beds.

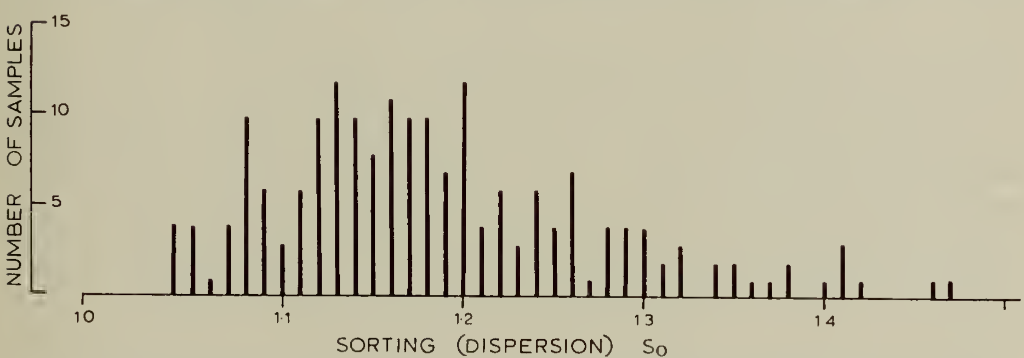

FIG. 47. Histogram of sorting values for Cardigan Bay sands. Note that low *So* values predominate. A lithified sand with such sorting and with negligible cement would be a desirable reservoir rock.

held by the operator who, often with very limited data, first predicts the trend pattern of the reservoir. Indeed, the need to predict, accurately, the pattern of clastic reservoirs, i.e., those controlled by sedimentation, is a prime requisite for successful exploration. We have seen that Cardigan Bay dispersal salients are chiefly related to the charted distribution of " reservoir type " sands. Thus, in attempting the prediction of sedimentary patterns in ancient sands, every effort should be made to secure such comparable textural and geochemical data as will provide a framework amenable to scalar and vector mapping.

While rigid mathematical treatment of dispersal data is a relatively easy task with modern computers, the use of vector algebra, trend surface maps, and the like, is not necessary if a simple graphic (vector) technique, such as used here, provides an objective, representative presentation. The initial attempt in plotting dispersal patterns should be the most straightforward one, often a simple graphic approach will suffice, retaining the detailed computations for complex problems and obscure relationships.

Moreover, the stratigrapher or economic geologist who wishes to apply the results of Recent sediment investigations, such as the present study of Cardigan Bay sands, should keep in mind that the studies of smaller areas are normally of much greater resolution. Thus, they should be used as interpretive guides only in light of the findings of other Recent sediment studies covering broad segments of depositional basins or shelves in order to achieve the proper perspective. Such excellent studies as those of van Andel (1960) and Koldewijn (1958) provide proportionately larger coverage, particularly for broad facies relationships. Furthermore, modern analytical approaches developed during the past few years have provided the marine sedimentologist with means which, when properly applied, allow him to differentiate between relict and modern deposits.

In short, results of this work and other Recent sediment studies provide criteria for interpreting ancient depositional environments; for predicting sedimentary patterns where a minimum of stratigraphic control is available, and for establishing local correlations.

IX. SUMMARY AND CONCLUSIONS

The results of this study suggest the following conclusions.

1. In the northern, sand-floored part of the area, bathymetry is controlled by the local sedimentation of sands introduced from beyond Sarn Badrig and from westwardly directed shore drift ; thus, net deposition over scour is responsible for the bathymetric high or shoaling zone extending southwestwardly from the landward end of Sarn Badrig. From this it may be concluded that, in shallow high energy environments, such as the present study area, bathymetric highs are related to sites of active transport and net deposition, and that some troughs, or bathymetric lows, are related to zones of scour or transport. In low energy environments, these associations are frequently reversed.

2. In spite of mountainous topography and high annual rainfall for the adjacent land, the majority of the detritus entering the bay is not derived from the nearby drainage area, but rather it is eroded from the shore exposures by the surf during winter gales, and to a lesser extent by normal beach waves during the remainder of the year. There is no evidence in the accumulated data of the mountainous landmass or of the abundant rainfall.

3. From a combined study of bathymetric and compositional data, and limited wave and current observations, it is concluded that tidal currents are the most important agents of sediment dispersal in the bay.

4. Texturally, the greater part of the survey area is floored by well sorted fine and medium grained sands ; there is no pronounced difference between a chart

based on contoured $\phi\ Mz$ measures and a chart based on simple facies grouping of similar textural types using a $\phi\ Mz$-based Wentworth nomenclature. In general, the finer grained sands are located closer to shore while the coarser grained sands are farther seaward. However, by charting the deposits according to the Niggli scheme, bimodal sand and gravel deposits are recognized. Thus, certain deposits classified as coarse sands, very coarse sands and granules by the single $\phi\ Mz$ measures are, in fact, mixtures of fine sand and fine gravel.

5. Coarse grained, poorly sorted sediments distributed northward from the seaward terminus of Sarn Wallog and mixed with fine sand suggest either a source of sediment associated with the erosion of the sarn, or of sediment transported into the area from the south of Sarn Wallog. Thus, the mixing of two sorted populations results in pronounced textural dispersion, and such a finding may be used to define the charted limits of polygenetic deposits, and aid in establishing their origin and paths of transport.

6. Thin sections of Recent sediments permit an inclusive, empirical grain classification scheme to be employed, thus providing a firm basis for charting specific grain type distributions and for classifying deposit types. This system is objective, singularly descriptive, flexible, and the grain count data can be charted to determine dispersal patterns.

7. The Pettijohn (1957, pp. 525–528) concept of dispersal shadows for clastic sediments is applicable to the sediments in the northern portion of Cardigan Bay. Thirteen grain types are good indicators of sediment origin and dispersal.

8. Photomicrographs of river samples for the Afon Dyfi show that the deposits are composed of slate fragments, whereas samples from the Dyfi estuary/river transition zone contain both fine grained quartz sand and fragments of both slates and arenites. Such observation permits the conclusion that estuary sand is derived from the bay—a conclusion which is also supported by geochemical evidence.

9. Photomicrographs of thin sections of samples adjacent to the Borth cliffs and samples from the bay floor show the presence of numerous grit fragments similar to the Aberystwyth greywacke beds exposed nearby. It is concluded that most, if not all, of the grit fragments in this bay area are derived from these coastal exposures.

10. Increase in the phyllosilicate content of a high energy sediment is related to the increase of lithic fragments alone.

11. Calcite in these high energy, nearshore sands is related to bioclastic debris and is added to the sediment system only at the site of deposition.

12. A composite dispersal plan for the northern portion of Cardigan Bay shows that three important sources of sediment are within the survey area : the cliffs of greywacke exposures near Borth, the low cliffs of glacial sediment exposed at Towyn, and the coastal exposures of glacial sediments north of Sarn Bwch. Sediments enter the survey area from without at the shoaling end of Sarn Badrig, near the seaward terminus of Sarn Badrig, near the seaward terminus of Sarn Wallog, and from beyond the western margin of the survey. The net transport of sand is northward with a partially developed counter-clockwise system in both the north part and south part of the survey. Moreover, the estuaries are being filled from the sea and not from the rivers.

13. In general, the composite dispersal plan based on grain types is the better indicator of sediment origin and distribution, while the element distribution plan is the better indicator of tidal currents and most active detrital transport zones.

14. In the present study, the majority of the Cardigan Bay sands are classified as sub-greywackes according to the van Andel scheme, but as quartzose sands according to the Pettijohn scheme. The latter categorization is preferred for Recent sediments.

15. The most mineralogically mature sediments are the fine sands with values between 2·0 and 2·5 ϕ *Mz.* These deposits include the maximum amount of quartz and the minimum amounts of both feldspars and phyllosilicates, and they are distributed in the zones of most active tidal current transport. They are the best sorted of the several textural groups, and while the total amount of quartz present in a sample (X-ray determined) is related to texture, no evidence suggests textural control of quartz dispersal. This finding greatly enhances the value of quartz in determining sedimentary dispersal.

16. Enrichment of zirconium in fine sands is related to zircon concentration (a lag deposit) in areas of most active bottom currents. Moreover, zirconium values exceeding about 400 or 500 ppm, in fine grained sands such as these, are indicative of high energy sedimentation.

17. The relationship between titanium content and median diameter is also related to the environment of sedimentation. Titanium is present in these deposits largely in the accessory mineral suite, and, as such, it is controlled by both texture and bottom currents. For most of these sediments with Md values below about 0·40 mm., and for all fine sands, titanium is present in the accessory suite ; however, for the deposits with Md values exceeding about 0·70 mm., titanium is also present in phyllosilicate minerals, chiefly within coarse slate fragments. Since coarse lithic fragments normally reflect high energy just as accessory minerals do in areas of fine sand alone, increased amounts of titanium in sediments such as these are correlative with increased tidal current energy.

18. A characteristic relationship exists between the amount of gallium present in a deposit and the sum total of phyllosilicates and feldspars. The amount of gallium replacement as well as the slope of the gallium/phyllosilicate-plus-feldspar regression does exhibit variations reflecting provenance control.

19. The sharp increase of titanium with the relatively small increase in iron is characteristic of high energy, well sorted sands, in which both iron and titanium are related mainly to the accessory mineral suite. Increase in titanium content of sand from approximately 1,000 ppm to 5,000 ppm with less than 3% increase in total iron, for sediments such as these, is significant evidence of the high energy nature of the depositional environment.

20. Increasing strontium with increasing calcium values is characteristic of these marine deposits and others of a similar nature.

21. The slope of the Ti/Zr regression for sediments from any one environment of deposition may be used to characterize the energy/sediment relation. Thus, sediments containing detrital clay and having an inverse Ti/Zr relationship characterize the " normal " low energy site of deposition, whereas positive correlation is charac-

teristic of a high energy environment. There are, of course, intermediate types between the two extremes.

22. The use of the scandium/gallium ratio aids in interpreting spectrochemical data relative to the probable provenance. Scandium and gallium represent an ideal example of the correlation of two trace elements which are genetically related to each other and to the provenance area.

23. It has been observed in the present study that a more or less constant ratio exists between cobalt and nickel. Thus, if the present study and others show agreement, and if Turekian & Wedepohl (1961) are correct in saying that many metamorphic rocks generally retain a trace element composition similar to their unmetamorphosed equivalent, the Co/Ni ratio should be a useful interpretative criterion for the study of metasediments.

24. Chemical elements present in Cardigan Bay sands are chiefly associated with the following compositional groups :

(1) Alumino-silicates : Al, Ba, Ga, K, Mg, Na, Sc, and minor amounts of B, Fe, Cr, Ti and V ;
(2) Accessory minerals : B, Co, Cr, Cu, Fe, Mn, Ni, Pb, Ti, V and Zr, and minor amounts of Pb and Sc ;
(3) Carbonate : Ca, Sr, and minor amounts of Mg, and possibly, Mn ; and
(4) Vein quartz : possibly, minor amounts of Cu and Pb.

25. Study of the petrographic data shows that associations of certain quartz types are common over distances of several miles in the fine sand facies. Thus, correlation of sub-surface sands should be possible over similar distances by analyzing conventional bore hole samples using the same petrographic method. Such a technique should prove useful in establishing local, but critical, correlations of sand bodies associated with oil field development.

26. The sands in the northern portion of Cardigan Bay possess the desirable sedimentary characteristics of a potential reservoir rock.

27. The results of this study suggest that the direction of dispersal and the direction of depositional slope are not always the same. Such an observation could be useful in interpreting the local paleogeography of ancient deposits.

28. The reported textural, compositional, and chemical data provide significant clues to sediment origin and dispersal; thus, the data should prove useful in comparative studies of similar, but lithified, sediments in the geological column.

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XI. REFERENCES

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TABLE III
(St. 1-57)

Station	Depth	Textural Statistics: Q1	Q3	Md	So	Sk	Ø16	ØM50	Ø84	ØMz	Øσg	ØMI	Basic X-ray Diffractogram Values: Mica	Chlorite	Quartz	Orthoclase	Plagioclase	Calcite	Dolomite	Background	X-ray Mineral Percentages: Mica	Chlorite	Quartz	Orthoclase	Plagioclase	Calcite	Dolomite	Phyllosilicates
1	6.0	0.22	0.16	0.20	1.17	0.88	2.0	2.3	2.7	2.3	0.35	2.3	2	6	78	9	12	10	5	15	2	3	77	5	6	5	2	5
2	6.0	0.20	0.18	0.19	1.05	1.00	2.2	2.4	2.5	2.3	0.15	2.3	2	7	79	9	7	11	7	14	2	4	77	5	4	6	2	6
6	3.0	0.32	0.22	0.26	1.20	1.04	1.4	1.9	2.3	1.8	0.45	1.8	3	9	77	5	6	8	3	14	3	5	81	3	3	4	1	8
7	4.0	0.19	0.17	0.18	1.06	0.99	2.3	2.5	2.6	2.4	0.15	2.4	1	5	77	8	7	8	4	14	1	3	82	5	4	4	1	4
9	5.5	0.21	0.17	0.18	1.13	1.10	2.0	2.4	2.7	2.3	0.35	2.3	3	6	78	9	10	8	2	15	3	3	80	4	5	4	1	6
10	6.5	0.20	0.17	0.18	1.08	1.05	2.2	2.5	2.6	2.4	0.20	2.4	2	6	84	9	7	7	3	13	2	3	81	5	4	4	1	5
11	8.0	0.22	0.16	0.18	1.17	1.09	1.8	2.5	2.8	2.3	0.50	2.3	2	4	67	8	9	11	8	14	2	2	75	5	6	7	3	4
12	9.5	0.25	0.18	0.20	1.18	1.12	1.8	2.3	2.6	2.2	0.40	2.2	2	5	82	6	5	9	4	14	2	3	83	3	3	5	1	5
14	10.5	0.24	0.18	0.22	1.15	0.89	1.9	2.2	2.6	2.2	0.35	2.2	2	7	72	6	8	9	4	16	2	4	79	3	5	6	1	6
15	12.0	7.4	0.19	0.50	1.97	5.64	-2.6	1.0	2.7	0.4	2.64	0.0	2	6	64	5	5	18	6	15	2	4	75	3	4	10	2	6
16	3.0	0.17	0.11	0.12	1.24	1.30	2.1	3.1	3.3	2.7	0.60	2.7	2	7	69	5	8	8	4	15	2	5	79	3	5	5	1	7
17	5.0	0.20	0.16	0.19	1.12	0.88	2.1	2.4	2.7	2.4	0.30	2.4	2	7	79	5	12	8	2	14	2	4	80	3	6	4	1	6
17-A	5.0	0.20	0.17	0.18	1.08	1.05	2.1	2.5	2.6	2.4	0.25	2.3	1	4	75	5	4	7	2	14	1	2	86	3	2	5	1	3
18	6.5	0.18	0.15	0.17	1.09	0.93	2.3	2.6	2.8	2.5	0.25	2.5	2	4	78	5	6	8	6	14	2	2	83	3	3	5	2	4
19	8.0	0.20	0.13	0.17	1.24	0.90	2.1	2.6	3.2	2.6	0.55	2.6	2	3	70	6	8	12	8	13	2	2	78	3	5	7	3	4
21	9.0	0.23	0.16	0.19	1.20	1.02	1.9	2.4	2.7	2.3	0.40	2.3	1	3	78	6	8	8	2	14	1	2	84	3	5	4	1	3
22	7.0	0.22	0.17	0.19	1.14	1.03	1.9	2.4	2.7	2.3	0.40	2.3	1	3	79	6	6	6	3	14	1	2	86	3	4	3	1	3
23	7.0	0.22	0.16	0.18	1.17	1.09	1.9	2.5	2.8	2.4	0.45	2.3	2	3	77	4	7	9	4	14	2	2	83	2	4	6	1	4
24	6.0	0.19	0.15	0.17	1.13	0.99	2.3	2.6	2.9	2.6	0.30	2.6	3	5	79	8	8	9	4	13	3	3	80	4	4	5	1	6
25	3.5	0.14	0.11	0.12	1.13	1.07	2.7	3.1	3.4	3.1	0.35	3.0	3	13	65	10	13	11	4	15	3	8	69	5	8	6	1	11
26	3.0	0.17	0.12	0.15	1.19	0.91	2.4	2.7	3.3	2.8	0.45	2.8	2	10	67	6	9	11	4	14	2	6	75	3	6	7	1	8
27	2.0	0.37	0.30	0.34	1.11	0.96	1.3	1.6	1.9	1.6	0.30	1.6	1	5	83	5	6	6	2	13	1	3	86	3	3	3	1	4
28	4.5	0.18	0.15	0.17	1.09	0.93	2.3	2.6	2.9	2.6	0.30	2.6	2	9	70	8	8	8	5	15	2	6	77	4	5	4	2	8
29	6.0	0.20	0.14	0.17	1.20	0.97	2.1	2.6	3.0	2.6	0.45	2.5	2	5	73	9	9	11	4	13	2	3	77	5	5	7	1	5
30	6.0	0.20	0.15	0.18	1.15	0.92	2.1	2.5	2.9	2.5	0.40	2.5	1	5	77	7	7	10	4	14	1	3	81	4	4	6	1	4
31	4.0	0.20	0.12	0.15	1.29	1.07	1.9	2.7	3.3	2.6	0.70	2.6	2	7	71	6	8	9	5	15	2	4	78	3	5	6	2	6
32	5.0	0.23	0.14	0.18	1.28	0.99	1.8	2.5	2.9	2.4	0.55	2.3	2	9	71	7	7	8	4	15	2	6	78	4	4	5	1	8
33	7.0	2.6	0.20	0.43	3.60	2.81	-2.2	1.2	3.0	0.7	2.60	0.4	10	32	48	2	7	10	3	20	12	19	56	1	5	6	1	31
34	6.0	0.38	0.07	0.21	2.27	0.63	1.2	2.3	4.0	2.5	1.40	2.6	5	17	46	2	7	15	3	18	7	12	62	1	6	11	1	19
35	4.0	0.34	0.19	0.24	1.34	1.12	1.9	2.1	2.6	2.2	0.35	2.2	1	3	84	4	4	10	3	14	1	2	87	2	2	5	1	3
36	8.0	0.43	0.30	0.36	1.19	0.86	0.9	1.5	1.8	1.1	0.45	1.3	1	4	80	4	8	10	2	14	1	2	84	2	4	6	1	3
37	3.0	0.20	0.16	0.18	1.12	0.99	2.1	2.5	2.7	2.4	0.30	2.4	2	5	74	6	8	9	4	15	2	3	81	3	4	6	1	5
38	6.0	0.23	0.17	0.19	1.16	1.08	1.9	2.4	2.6	2.3	0.35	2.2	2	4	75	4	6	7	2	15	2	2	85	2	3	5	1	4
39	5.0	0.23	0.17	0.19	1.16	1.08	1.9	2.4	2.7	2.3	0.40	2.3	1	4	79	8	6	7	3	15	1	2	84	5	3	4	1	3
41	6.0	0.26	0.17	0.20	1.24	1.10	1.7	2.3	2.7	2.2	0.50	2.2	2	4	76	7	10	7	2	14	2	2	81	4	6	4	1	4
46	8.0	0.29	0.20	0.24	1.20	1.01	1.6	2.1	2.5	2.1	0.45	2.0	1	3	77	5	6	9	3	14	1	2	84	3	3	6	1	3
47	9.0	1.1	0.23	0.46	2.21	1.21	-1.1	1.1	2.5	0.8	1.80	0.7	2	5	72	6	9	12	3	15	2	3	79	3	5	7	1	5
48	12.0	0.54	0.34	0.43	1.26	0.99	0.8	1.2	1.7	1.2	0.45	1.2	2	3	72	2	5	11	4	15	2	2	83	1	3	7	2	4
49	11.0	0.32	0.22	0.26	1.20	1.04	1.4	1.9	2.4	1.9	0.50	1.9	1	2	83	3	3	10	3	15	1	1	88	2	2	5	1	2
50	4.0	0.15	0.12	0.14	1.12	0.92	2.6	2.8	3.2	2.8	0.30	2.9	2	8	69	3	6	9	5	16	2	5	80	2	4	5	2	7
51	5.0	0.20	0.16	0.18	1.12	0.99	2.2	2.5	2.7	2.5	0.25	2.4	1	4	69	6	6	11	4	16	1	2	81	4	4	7	1	3
52	8.0	0.22	0.16	0.18	1.17	1.09	1.9	2.5	2.7	2.4	0.40	2.3	1	4	68	5	5	9	5	15	1	2	81	4	4	6	2	3
53	7.5	0.28	0.16	0.21	1.32	1.01	-1.4	2.3	2.8	1.2	2.10	0.7	2	6	62	6	6	12	5	15	3	4	76	4	4	7	2	7
54	8.5	0.23	0.17	0.19	1.16	1.08	1.9	2.4	2.6	2.3	0.35	1.2	3	7	77	6	7	8	3	14	3	4	81	3	4	4	1	7
55	8.0	0.29	0.20	0.24	1.20	1.01	1.6	2.1	2.6	2.1	0.50	2.1	2	5	83	5	5	8	3	14	2	3	84	3	3	4	1	5
56	8.0	0.21	0.18	0.19	1.08	1.05	2.1	2.4	2.6	2.4	0.25	2.3	2	3	80	5	5	7	3	13	2	2	85	3	3	4	1	4
57	7.0	0.23	0.18	0.19	1.13	1.15	1.8	2.4	2.5	2.2	0.40	2.2	2	2	69	6	6	8	3	15	2	1	83	4	4	5	1	3

Station	Optical Petrography, Grain Types, Percentages: Feldspars	Carbonates	Quartz 1	Quartz 2	Quartz 3	Quartz 4	Quartz 5	Quartz 6	Quartz 7	Quartz 8	Quartz 9	Quartz 10	Quartz 11	Quartz 12	Quartz 13	Quartz 14	Quartz 15	Quartz 16	Carbonates	Arenites	Shale-slate	Crystallines	Chert	Feldspars
1	11	7	24.6	5.7	2.8	4.9	2.4	4.9	5.3	9.0	3.2	4.5	0.8	0.0	7.7	0.4	2.0	2.8	4.9	5.7	0.8	1.2	1.6	3.8
2	9	8	21.2	4.9	3.5	2.4	3.1	5.3	2.1	6.7	5.6	3.5	1.4	0.0	6.2	0.6	1.6	2.8	9.5	10.0	2.4	0.7	2.1	4.4
6	6	5	21.3	4.0	0.7	3.3	3.7	3.7	4.0	9.2	4.0	8.8	2.9	1.1	6.0	0.6	2.0	1.4	3.6	15.8	1.1	0.0	1.1	1.7
7	9	5	24.8	2.4	0.3	2.1		0.9	21.8	11.2	2.4	3.0	1.8	1.8	0.9	1.2	0.6	0.3	2.7	8.1	3.0	2.1	0.9	8.8
9	9	5	23.0	8.5	3.1	4.6	2.8	5.3	2.8	6.7	1.4	9.2	2.1	0.3	4.6	0.3	0.6	1.0	2.8	11.0	4.2	0.3	0.3	2.4
10	9	5	16.3	5.2	3.1	0.6	0.6	0.3	22.1	13.8	7.6	1.8	1.2	1.8	1.2	0.9	0.0	0.6	4.6	6.1	4.0	0.6	0.0	7.6
11	11	10	21.0	4.6	1.8	0.3	0.6	1.2	23.0	9.5	7.4	1.8	1.5	1.2	1.5	0.6	0.6	0.6	3.4	4.3	6.1	0.9	0.0	8.0
12	6	6	20.2	7.0	6.0	6.4	1.7	5.7	1.7	9.1	1.7	13.1	0.6	0.0	2.7	0.3	2.9	1.0	3.0	7.4	2.0	0.6	1.7	5.2
14	8	7	17.1	5.8	3.8	8.0	3.2	3.2	2.6	13.8	4.5	4.5	2.6	0.0	4.4	0.6	1.3	0.3	2.6	8.0	6.4	2.2	2.6	3.5
15	7	12	20.6	2.8	1.5	0.3	1.8	0.6	18.7	8.0	5.2	2.8	0.6	1.2	0.9	1.2	0.9	0.0	8.2	8.9	6.7	1.5	0.3	7.3
16	8	6	15.6	6.0	4.1	4.4	2.5	6.7	2.5	11.1	6.7	4.7	1.6	0.6	4.7	0.0	0.3	0.6	3.1	7.0	9.2	0.9	1.6	6.1
17	9	5	12.0	10.0	3.9	5.2	1.0	4.5	3.2	11.3	3.5	8.1	0.3	0.0	5.4	0.0	0.6	0.6	5.5	9.4	6.8	0.0	2.6	6.1
17-A	5	6	14.7	5.2	4.0	6.0	1.3	3.0	7.7	12.7	3.0	6.3	0.0	0.0	6.6	0.3	0.3	0.3	4.6	9.3	4.7	0.0	2.3	7.7
18	6	7	13.6	6.0	4.0	4.3	0.6	2.6	6.6	15.0	8.0	7.7	0.0	0.3	4.6	0.0	1.0	1.0	4.6	8.6	5.3	0.6	1.0	4.6
19	8	10	25.6	4.7	2.8	4.6	0.3	0.6	8.6	11.8	5.4	3.2	0.0	0.0	0.9	0.0	0.3	0.3	4.3	10.8	6.0	0.9	1.8	7.3
21	8	5	18.6	3.7	7.8	1.5	0.7	4.8	6.7	12.3	10.0	6.7	0.3	0.3	1.1	0.0	0.7	0.7	3.7	11.0	2.6	0.7	2.6	3.5
22	7	4	19.7	4.5	2.7	3.6	0.9	2.4	8.7	11.4	6.9	4.5	0.6	1.8	3.6	0.0	2.1	0.3	0.3	11.1	7.8	0.0	0.6	6.5
23	6	7	24.6	3.9	2.0	3.3	1.3	1.6	6.9	9.9	8.9	3.9	0.6	1.6	4.2	0.9	0.9	0.0	3.5	7.2	6.5	0.0	2.0	6.3
24	8	6	19.4	2.9	0.3	1.8	0.8	3.7	9.3	15.2	4.8	4.8	0.8	1.3	3.8	0.3	0.9	0.0	5.1	7.4	7.5	1.3	4.0	4.6
25	13	7	16.8	4.6	2.4	0.3	1.2	4.9	9.5	6.1	2.7	1.2	0.6	0.3	3.3	0.0	0.3	0.0	7.0	14.1	14.7	0.9	4.0	5.0
26	9	8	16.0	5.4	2.2	2.2	1.1	4.1	6.8	11.4	6.0	1.9	0.3	0.3	1.4	0.6	0.6	0.5	3.2	17.9	12.5	1.1	1.6	2.9
27	6	4	16.0	7.2	4.7	2.2	1.5	2.2	11.3	11.0	6.9	5.0	1.8	1.5	1.8	2.5	0.3	0.3	1.8	11.9	4.0	1.2	1.2	3.7
28	9	6	21.8	3.9	1.3	1.3	0.6	1.3	11.5	12.8	3.3	3.9	1.0	2.3	2.3	0.3	0.6	0.3	3.9	11.5	8.8	0.6	1.0	5.7
29	10	8	26.1	4.0	2.7	1.7	2.3	4.0	8.5	7.8	7.1	3.0	1.0	0.0	5.3	0.3	0.6	0.7	4.7	5.7	5.4	2.0	0.7	6.4
30	8	7	32.2	3.9	5.7	0.9	1.8	0.0	16.2	5.4	6.3	0.9	0.9	0.3	1.8	0.0	0.9	0.3	6.6	2.4	5.7	0.9	0.3	6.6
31	8	8	32.8	3.5	1.6	0.3	1.6	3.2	5.7	8.9	4.7	1.9	1.6	0.0	2.8	0.3	0.6	0.0	6.0	10.0	5.7	1.6	1.6	6.6
32	8	6	27.2	4.2	2.1	1.8	1.5	2.1	10.0	12.4	3.6	2.7	0.6	0.9	3.0	0.3	0.6	0.6	2.7	7.8	8.7	0.6	0.9	5.7
33	6	7	34.7	5.7	6.6	1.5	1.5	0.6	10.6	3.3	4.2	1.8	3.0	0.6	2.4	0.3	0.9	0.3	3.6	6.0	4.5	0.9	0.0	7.0
34	7	12	n.d.	n.d.	n.d.	n.d.	n.d	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
35	4	6	21.2	4.6	2.3	1.6	2.0	2.3	15.0	10.0	6.6	6.3	1.3	1.3	3.3	0.7	0.3	0.0	4.3	5.3	4.0	0.3	1.6	5.7
36	6	7	26.5	5.9	3.0	0.3	1.2	1.5	11.0	11.9	5.3	2.4	0.6	0.6	3.6	0.3	1.8	0.6	4.7	8.0	6.5	0.0	1.2	5.7
37	7	7	23.4	5.6	1.6	1.3	0.6	2.0	10.3	15.5	6.3	3.0	0.3	0.3	2.6	0.6	0.9	0.0	4.6	6.9	7.3	0.9	0.6	3.4
38	5	6	31.6	6.4	4.9	0.6	0.3	1.5	9.8	8.3	5.2	1.2	1.5	1.2	0.6	1.2	0.3	0.6	2.4	7.3	5.2	4.0	0.0	5.9
39	8	5	27.9	7.2	1.9	2.3	1.9	1.3	6.5	11.8	11.5	1.9	1.0	1.3	2.9	0.0	0.3	0.3	5.9	8.8	2.2	0.3	0.0	2.6
41	10	5	37.1	4.4	0.3	0.0	0.9	0.0	23.2	9.8	2.2	0.6	1.6	0.9	0.9	1.2	0.0	0.0	0.6	6.0	1.2	1.6	0.6	6.9
46	6	7	49.7	5.5	0.0	0.0	1.5	0.0	13.9	8.0	1.5	1.2	1.2	0.3	0.6	1.2	0.3	0.0	2.7	0.6	1.8	1.2	2.1	6.7
47	8	8	33.0	5.1	0.0	0.6	1.2	0.3	25.8	8.7	0.9	1.5	0.9	0.9	1.8	1.5	0.0	0.3	5.1	4.2	2.1	0.0	1.2	4.8
48	4	9	31.7	4.0	8.1	2.6	1.4	4.4	5.1	7.7	4.0	2.6	1.4	0.3	2.2	0.0	0.3	0.4	7.3	8.1	1.4	1.4	1.4	4.2
49	4	6	23.6	10.9	5.4	2.1	1.2	0.6	14.5	11.5	8.5	2.1	0.3	0.6	1.2	0.3	0.9	0.0	3.3	5.4	3.6	0.0	0.6	3.4
50	6	7	15.8	5.4	5.7	0.3	1.2	0.9	9.3	9.3	7.8	2.4	0.6	1.2	3.3	0.3	0.6	0.3	5.4	9.9	11.6	0.9	2.4	5.4
51	8	8	22.8	7.1	5.6	0.6	1.5	0.9	8.9	9.8	10.1	1.5	1.2	0.3	2.4	0.9	0.0	0.3	7.7	7.4	3.5	0.3	2.1	5.1
52	8	8	27.0	6.6	2.5	1.9	0.0	1.2	9.5	11.4	5.0	3.8	1.2	0.0	2.5	0.6	0.6	0.0	5.7	8.2	4.7	1.2	1.2	4.2
53	8	9	15.6	4.5	8.1	0.6	0.9	0.9	9.0	7.8	9.6	3.0	3.0	1.5	2.7	0.6	0.9	0.3	8.7	9.0	6.9	0.6	0.9	4.9
54	7	5	25.4	4.8	3.9	0.6	0.8	1.1	10.7	8.5	9.0	3.4	2.5	0.3	1.7	0.3	0.9	0.3	5.6	10.1	4.3	0.6	1.4	3.8
55	6	5	18.1	4.1	2.0	0.9	1.7	1.1	16.1	15.0	4.9	5.2	2.3	2.3	1.7	0.6	0.3	0.9	5.5	7.9	3.8	0.3	0.9	4.4
56	6	5	20.4	8.1	4.6	3.2	1.7	0.6	9.0	8.7	8.5	3.8	1.1	0.6	2.5	0.6	0.3	0.5	6.4	9.0	4.4	0.0	0.9	4.9
57	8	6	28.0	6.8	4.4	2.1	0.0	0.3	7.4	10.1	6.5	2.1	0.3	1.2	4.5	0.6	0.6	0.6	5.3	6.8	3.2	0.0	0.6	8.6

Station	Chemical Elements, Spectrographic: Aluminum	Boron	Barium	Calcium	Cobalt	Chromium	Copper	Iron	Gallium	Potassium	Magnesium	Manganese	Sodium	Nickel	Lead	Scandium	Strontium	Titanium	Vanadium	Zirconium
1	5.4	32	55	3.25	4.0	24	21.0	1.70	2.6	0.38	0.50	490	0.32	10.5	18	5.2	150	2150	39	400
2	4.7	43	87	3.13	4.9	53	24.0	2.00	3.6	0.42	0.46	495	0.42	14.4	29	6.8	138	3100	50	810
6	4.5	24	45	2.90	4.9	18	44.0	2.00	2.9	0.29	0.41	340	0.38	13.0	11	5.0	140	1350	42	110
7	3.9	40	51	2.33	4.4	23	12.0	1.80	2.7	0.38	0.37	300	0.40	13.2	8	5.1	106	1850	45	130
9	4.8	31	110	3.30	4.8	31	9.8	2.00	3.4	0.42	0.45	345	0.44	13.5	17	5.8	172	1980	51	380
10	2.9	34	99	2.26	4.4	21	5.0	1.85	2.8	0.39	0.34	300	0.46	11.3	5	4.2	103	1260	41	78
11	3.6	75	122	2.58	4.8	107	11.1	2.94	3.7	0.37	0.35	580	0.46	26.2	12	11.4	112	5800	67	2500
12	4.3	32	103	2.90	5.0	27	5.3	1.99	2.9	0.24	0.40	375	0.32	12.1	16	5.8	138	1570	49	190
14	3.1	43	174	2.20	4.8	160	9.9	3.52	3.9	0.36	0.32	710	0.36	29.7	21	11.0	135	5100	77	2100
15	4.4	42	310	4.15	6.1	57	63.5	2.90	5.7	0.60	0.45	380	0.82	19.5	38	6.2	230	1450	60	225
16	3.6	59	200	2.35	6.0	111	36.0	3.20	4.5	0.47	0.37	475	0.52	25.0	40	10.0	129	3570	64	1510
17	3.5	28	76	2.57	5.1	34	16.5	2.25	3.4	0.38	0.38	475	0.39	13.0	38	5.7	130	1700	51	195
17-A	2.9	56	92	2.38	4.6	66	21.0	2.69	3.6	0.35	0.33	465	0.42	18.2	15	8.0	104	3600	61	1120
18	3.6	39	130	2.70	4.6	29	30.0	1.95	3.0	0.35	0.39	370	0.49	11.8	24	5.8	130	2250	45	195
19	4.4	41	155	3.50	4.9	56	16.2	2.50	4.2	0.45	0.42	440	0.57	17.9	32	7.6	173	2950	51	675
21	3.5	28	46	2.58	4.4	21	8.1	1.80	2.7	0.29	0.36	365	0.37	12.0	17	4.2	126	1300	41	150
22	3.3	42	130	2.45	4.6	38	6.5	2.03	3.2	0.30	0.40	375	0.37	12.7	13	4.3	113	2050	44	290
23	4.0	54	70	2.50	4.4	45	9.8	2.10	3.0	0.34	0.45	400	0.34	12.5	17	5.8	134	2650	48	315
24	3.6	35	125	2.88	4.2	39	12.3	1.94	2.7	0.40	0.43	328	0.46	12.9	21	4.1	146	1800	41	195
25	6.2	37	260	3.05	7.3	81	33.0	3.17	6.6	0.68	0.46	475	0.74	26.2	62	12.3	164	3600	60	1020
26	3.6	46	170	2.21	7.4	62	22.0	3.09	5.3	0.56	0.33	580	0.58	21.2	47	7.4	120	3100	56	680
27	2.1	21	25	1.68	4.2	15	8.2	1.86	2.3	0.20	0.29	250	0.29	10.4	17	3.9	100	740	37	83
28	4.3	47	185	2.28	6.8	106	17.8	3.24	5.2	0.52	0.36	530	0.57	23.8	37	9.8	108	4100	65	1180
29	3.5	35	200	2.57	4.9	38	19.0	2.25	3.7	0.49	0.37	490	0.55	12.6	31	4.2	130	2000	44	400
30	3.9	41	117	2.80	4.9	35	13.4	2.15	3.0	0.36	0.40	495	0.38	13.0	26	4.9	135	2450	48	320
31	4.0	40	200	2.77	5.9	64	21.0	2.79	4.5	0.41	0.33	495	0.52	18.0	38	8.1	130	3400	57	850
32	3.7	48	110	2.10	5.0	33	12.0	2.21	4.2	0.44	0.36	480	0.46	14.4	26	5.4	97	1920	49	330
33	12.0	53	440	3.40	10.8	58	48.0	4.29	13.8	1.00	0.84	700	1.22	35.4	93	15.8	169	2800	73	80
34	14.5	72	330	4.55	11.2	69	72.0	4.81	14.5	1.60	0.66	480	1.68	38.0	85	14.6	212	3200	91	200
35	3.1	82	70	2.66	4.6	17	18.6	1.85	2.3	0.27	0.35	500	0.35	11.0	18	3.8	129	1350	43	200
36	3.4	30	80	2.95	7.5	25	7.8	2.80	3.2	0.28	0.41	650	0.40	17.9	25	4.4	154	1010	57	73
37	3.0	34	110	2.13	5.6	95	15.7	2.60	3.2	0.31	0.31	500	0.43	29.8	22	9.5	114	3450	62	2630
38	3.0	28	115	1.75	7.2	28	12.0	2.25	3.6	0.37	0.33	590	0.51	13.2	30	5.0	94	1350	58	103
39	2.7	47	95	1.68	6.5	30	9.3	2.55	3.0	0.35	0.34	560	0.44	15.5	25	5.9	111	1920	58	275
41	3.1	27	45	1.93	5.3	18	9.2	1.89	2.5	0.28	0.36	520	0.38	11.8	22	5.0	99	1370	48	113
46	2.4	33	70	1.99	3.7	39	7.3	1.65	2.3	0.23	0.34	267	0.29	10.7	7	4.0	115	1330	36	170
47	4.8	26	150	4.10	5.8	48	14.0	2.70	3.8	0.28	0.55	565	0.38	17.4	13	5.2	207	1740	57	195
48	3.1	21	85	3.75	5.6	20	6.8	2.25	2.1	0.17	0.51	500	0.27	13.0	14	3.0	190	670	52	74
49	2.5	31	70	2.55	4.4	29	5.4	2.03	2.1	0.19	0.39	297	0.26	13.0	5	4.1	126	1030	48	80
50	4.2	35	160	2.40	6.7	68	10.7	2.79	4.6	0.40	0.39	470	0.50	18.6	39	7.0	113	2850	56	600
51	3.4	85	170	2.37	5.2	137	8.5	3.00	3.9	0.39	0.38	570	0.48	18.5	16	9.5	105	5150	67	750
52	3.7	68	150	2.77	5.0	94	8.3	2.59	3.7	0.33	0.44	470	0.42	18.4	13	8.1	131	3800	60	1080
53	4.6	42	210	2.65	6.8	160	13.0	3.30	5.1	0.39	0.39	500	0.52	31.0	18	15.0	113	4200	73	2360
54	3.2	36	75	2.30	4.7	30	5.3	1.95	3.2	0.51	0.36	375	0.34	12.0	11	5.3	106	1600	50	140
55	2.2	33	30	1.78	4.5	22	9.4	1.95	2.4	0.35	0.30	365	0.30	11.3	9	3.9	86	1500	44	150
56	2.2	32	70	2.05	4.2	17	6.8	1.60	2.3	0.37	0.30	325	0.35	10.8	15	3.8	89	1200	38	98
57	2.5	39	130	1.95	5.2	177	6.3	3.75	3.0	0.39	0.32	500	0.31	25.5	13	9.3	96	4600	81	2100

TABLE IV
(St. 58–117)

Station	Depth	Q1	Q3	Md	So	Sk	Ø16	ØM50	Ø84	ØMz	Øσg	ØMI	Mica	Chlorite	Quartz	Orthoclase	Plagioclase	Calcite	Dolomite	Background	Mica	Chlorite	Quartz	Orthoclase	Plagioclase	Calcite	Dolomite	Phyllosilicates	Feldspars	Carbonates
		Textural Statistics											Basic X-ray Diffractogram Values								X-ray Mineral Percentages									
58	7.0	0.21	0.17	0.18	1.13	1.10	2.1	2.5	2.7	2.4	0.30	2.4	2	3	79	5	6	8	5	13	2	2	84	3	3	4	2	4	6	6
59	7.0	0.22	0.16	0.18	1.17	1.08	1.9	2.5	2.8	2.4	0.45	2.3	1	3	77	5	6	9	3	15	1	2	84	3	3	6	1	3	6	7
60	6.5	0.22	0.15	0.18	1.21	1.02	2.0	2.5	2.9	2.5	0.45	2.4	2	4	74	6	5	9	3	16	2	2	83	3	3	6	1	4	6	7
61	6.0	0.22	0.13	0.17	1.30	0.99	1.9	2.6	3.2	2.5	0.65	2.5	2	3	72	7	5	9	3	16	2	2	81	5	3	6	1	4	8	7
62	6.0	0.74	0.23	0.41	1.79	1.01	-0.1	1.3	2.8	1.3	1.45	1.3	6	14	52	3	5	10	2	20	8	9	69	3	4	6	1	17	7	7
63	6.5	0.23	0.14	0.18	1.28	0.99	1.9	2.5	2.9	2.4	0.50	2.4	1	5	75	6	8	10	3	16	1	3	82	3	4	6	1	4	7	7
64	6.0	0.37	0.27	0.32	1.17	0.98	1.3	1.7	2.0	1.6	0.35	1.6	2	6	80	4	3	7	2	14	2	3	86	2	2	4	1	5	4	5
65	6.0	0.22	0.14	0.18	1.25	0.95	2.0	2.5	2.9	2.5	0.45	2.4	2	3	74	5	6	10	4	14	2	2	83	3	3	6	1	4	6	7
66	7.0	0.22	0.13	0.17	1.30	0.99	2.0	2.6	3.1	2.6	0.55	2.5	2	4	70	6	6	10	4	15	2	2	82	3	4	6	1	4	7	7
67	6.0	0.23	0.14	0.18	1.28	0.99	1.9	2.5	3.1	2.5	0.60	2.5	1	4	63	5	5	9	3	18	1	3	81	4	4	6	1	4	8	7
68	7.0	0.19	0.16	0.18	1.09	0.94	2.2	2.5	2.7	2.5	0.25	2.4	3	4	77	5	6	13	4	14	3	2	81	3	3	7	1	5	6	8
69	5.0	0.20	0.15	0.17	1.15	1.04	2.1	2.6	2.9	2.5	0.40	2.5	2	3	81	7	6	10	4	15	2	2	83	4	3	5	1	4	7	6
71	6.0	1.1	0.23	0.35	2.16	2.07	-0.8	1.5	2.3	1.0	1.55	0.7	3	7	67	4	7	13	2	15	3	5	77	2	4	8	1	8	6	9
72	6.0	0.21	0.15	0.18	1.18	0.97	1.9	2.5	2.8	2.4	0.45	2.3	2	3	74	4	6	8	3	14	2	2	84	2	4	5	1	4	6	6
73	6.0	0.22	0.15	0.18	1.18	1.02	2.0	2.5	2.8	2.4	0.40	2.4	1	3	77	6	5	8	3	14	1	2	85	3	3	5	1	3	6	6
74	6.0	0.22	0.16	0.19	1.17	0.97	1.9	2.4	2.8	2.3	0.45	2.3	2	4	72	5	4	9	3	16	2	2	83	4	2	6	1	4	6	7
75	8.0	0.21	0.16	0.18	1.14	1.03	2.0	2.5	2.8	2.4	0.40	2.4	1	3	77	6	5	7	5	14	1	2	84	3	3	5	2	3	6	7
76	7.5	0.23	0.17	0.19	1.16	1.08	1.9	2.4	2.7	2.3	0.40	2.3	2	4	72	8	7	8	4	15	2	2	81	5	4	5	1	4	9	6
77	8.0	0.24	0.16	0.19	1.22	1.06	1.8	2.4	2.7	2.3	0.45	2.2	2	3	77	6	6	9	3	14	2	2	83	3	3	6	1	4	6	7
78	8.0	0.23	0.17	0.19	1.16	1.08	1.8	2.4	2.7	2.3	0.45	2.2	1	3	81	6	4	8	2	14	1	2	87	3	2	4	1	3	5	5
79	10.0	0.31	0.22	0.25	1.19	1.09	1.4	2.0	2.3	1.9	0.45	1.8	3	4	72	5	4	9	2	14	3	2	82	4	2	6	1	5	6	7
80	8.5	0.27	0.20	0.23	1.16	1.02	1.7	2.1	2.5	2.1	0.40	2.1	2	4	80	5	8	9	3	14	2	2	83	3	4	5	1	4	7	6
81	8.0	0.20	0.17	0.18	1.08	1.05	2.2	2.5	2.6	2.4	0.20	2.4	3	5	76	8	8	6	2	15	3	3	81	4	5	3	1	6	9	4
85	8.0	0.34	0.17	0.20	1.41	1.44	0.8	2.3	2.6	1.9	0.90	1.7	2	5	72	4	5	9	3	15	2	3	82	2	4	6	1	5	6	7
86	8.0	0.28	0.22	0.25	1.13	0.98	1.7	2.0	2.3	2.0	0.30	2.0	2	5	77	5	5	6	2	15	2	3	84	3	3	4	1	5	6	5
87	7.5	0.28	0.22	0.25	1.13	0.98	1.7	2.0	2.4	2.0	0.35	2.0	2	4	72	3	6	8	3	15	2	2	84	2	4	5	1	4	6	6
88	6.0	0.26	0.20	0.23	1.14	0.98	1.8	2.1	2.5	2.1	0.35	2.1	2	4	82	6	5	7	2	15	2	2	85	3	3	4	1	4	6	5
89	6.0	0.20	0.16	0.18	1.12	0.99	2.2	2.5	2.7	2.5	0.25	2.4	1	3	76	6	8	8	2	14	1	2	84	3	5	4	1	3	8	5
90	6.0	0.24	0.16	0.19	1.22	1.06	1.8	2.4	2.6	2.3	0.40	2.2	2	5	79	8	8	9	3	15	2	3	81	4	4	5	1	5	8	6
92	4.0	0.20	0.16	0.18	1.12	0.99	1.9	2.5	2.8	2.4	0.45	2.3	2	4	81	7	11	9	4	14	2	2	80	4	6	5	1	4	10	6
93	3.5	0.18	0.11	0.15	1.28	0.88	2.3	2.7	3.3	2.8	0.50	2.8	2	6	68	6	9	10	6	14	2	4	77	3	6	6	2	6	9	8
94	4.0	0.27	0.15	0.19	1.34	1.12	1.4	2.4	2.9	2.2	0.75	2.1	2	4	75	7	6	8	4	14	2	2	83	4	3	5	1	4	7	6
95	4.0	0.19	0.11	0.15	1.31	0.93	2.3	2.7	3.3	2.8	0.50	2.8	2	5	72	11	8	11	4	15	2	3	77	6	4	7	1	5	10	8
97	8.5	0.90	0.21	0.30	2.07	2.10	-1.8	1.7	2.5	0.8	2.15	0.3	4	10	66	4	10	12	2	18	4	6	74	2	6	7	1	10	8	8
98	8.0	0.32	0.19	0.25	1.30	0.97	1.4	2.0	2.6	2.0	0.60	2.0	3	6	69	4	6	10	3	15	3	4	80	2	4	6	1	7	6	7
99	6.0	0.29	0.19	0.23	1.23	1.04	1.7	2.1	2.6	2.1	0.45	2.1	2	5	75	3	5	8	4	15	2	5	75	2	3	5	1	5	5	6
100	7.0	0.27	0.18	0.21	1.22	1.10	1.7	2.3	2.6	2.2	0.45	2.1	2	4	78	7	7	8	4	14	2	2	82	4	4	5	1	4	8	6
101	7.0	0.19	0.17	0.18	1.06	0.99	2.3	2.5	2.6	2.5	0.15	2.4	2	3	73	5	6	9	3	15	2	2	82	3	4	6	1	4	7	7
102	2.5	0.20	0.12	0.16	1.29	0.94	2.1	2.6	3.3	2.6	0.60	2.7	2	6	73	7	10	15	3	15	2	3	77	4	5	8	1	5	9	9
103	4.0	0.19	0.10	0.13	1.38	1.12	2.1	2.9	3.4	2.8	0.65	2.7	3	8	70	9	12	11	5	15	3	4	73	5	7	6	2	7	12	8
104	2.0	11.0	0.34	6.8	5.68	0.08	-3.7	-2.8	2.4	-1.3	3.05	-0.6	7	26	57	1	13	12	2	19	8	14	62	1	7	7	1	22	8	8
108	6.0	19.0	1.1	12.0	4.15	0.14	-4.4	-3.6	1.9	-2.0	3.15	-1.2	4	11	70	5	8	11	4	17	4	6	75	3	4	7	1	10	7	8
109	2.0	26.0	4.7	7.8	2.34	2.01	-5.2	-2.9	-1.2	-3.1	2.00	-3.2	13	47	40	0	19	5	0	25	14	27	45	0	11	3	0	41	11	3
113	6.0	6.8	1.8	4.4	1.94	0.63	-3.0	-2.1	1.4	-1.2	2.20	-0.8	7	23	50	2	17	7	6	21	8	14	59	1	11	5	2	22	12	7
115	11.0	0.27	0.19	0.23	1.19	0.97	1.8	2.1	2.6	2.2	0.40	2.2	2	4	65	7	7	8	4	13	2	3	79	5	5	5	1	5	10	6
116	11.0	0.22	0.16	0.17	1.17	1.22	1.8	2.6	2.7	2.3	0.45	2.2	1	3	54	8	5	7	3	13	1	3	79	6	4	6	1	4	10	7
117	11.0	5.2	0.25	1.7	4.56	0.45	-2.8	-0.7	2.4	-1.0	2.60	-0.2	4	7	44	1	10	11	4	13	6	6	68	2	8	8	2	12	10	10

Station	Quartz 1	Quartz 2	Quartz 3	Quartz 4	Quartz 5	Quartz 6	Quartz 7	Quartz 8	Quartz 9	Quartz 10	Quartz 11	Quartz 12	Quartz 13	Quartz 14	Quartz 15	Quartz 16	Carbonates	Arenites	Shale-slate	Crystallines	Chert	Feldspars
	Optical Petrography, Grain Types, Percentages																					
58	41.5	3.9	3.2	3.2	0.9	1.6	6.7	6.7	5.4	1.6	0.6	0.0	2.8	0.3	0.0	0.0	3.9	9.6	4.4	0.0	0.6	3.1
59	23.6	6.1	4.2	1.8	0.9	1.2	17.0	9.1	5.8	3.3	0.6	0.9	2.7	0.9	1.8	0.0	4.5	6.1	5.4	0.0	0.3	3.8
60	21.4	7.2	7.5	2.4	0.6	0.9	10.5	5.7	10.0	2.7	1.5	0.6	2.1	0.6	1.2	0.0	4.8	7.2	5.4	0.3	0.9	6.5
61	29.2	4.2	3.0	1.5	0.6	3.0	11.4	7.6	6.4	3.9	0.9	2.1	3.0	0.3	0.3	0.6	4.8	7.0	5.1	0.3	0.6	4.2
62	25.3	4.5	2.7	2.7	0.9	0.9	12.8	8.6	2.7	3.3	0.9	1.8	2.4	0.3	0.0	0.0	6.5	9.8	8.0	1.8	2.4	1.7
63	27.0	3.4	3.1	0.6	0.0	1.1	18.4	7.1	8.5	4.5	0.8	0.3	2.2	0.3	0.0	0.3	5.4	6.5	5.9	0.3	0.3	3.7
64	17.9	3.0	0.3	0.9	0.3	8.9	21.2	10.0	5.4	8.8	2.1	1.5	0.9	0.0	0.0	0.0	4.5	11.8	5.4	0.6	0.9	3.0
65	17.5	4.2	0.6	0.6	0.6	1.2	18.1	15.1	9.0	4.5	0.6	0.6	0.0	0.0	0.3	0.0	5.1	13.3	3.6	0.3	1.2	3.9
66	16.7	5.5	1.8	1.8	0.0	0.9	17.6	17.0	7.6	4.2	0.6	1.2	1.5	0.0	0.3	0.3	3.0	10.3	4.2	0.6	1.2	3.7
67	27.1	4.1	2.4	0.6	0.3	0.6	17.3	13.7	4.1	4.8	0.3	0.3	0.3	0.3	0.3	0.0	3.6	8.6	2.7	0.0	0.9	7.7
68	25.0	4.2	1.2	1.5	0.6	1.8	19.0	14.8	3.9	5.4	0.3	0.3	2.1	0.3	0.0	0.0	6.0	5.7	4.2	0.9	0.3	2.5
69	25.4	3.2	0.6	1.6	0.0	0.0	17.8	14.0	3.5	4.8	0.3	0.3	1.9	0.6	0.0	0.3	7.0	8.2	3.4	0.3	0.6	6.2
71	21.0	7.5	1.8	0.6	0.6	1.2	18.3	11.4	6.0	5.4	0.3	1.2	1.8	0.3	0.6	0.6	5.1	9.6	1.5	1.5	0.9	2.8
72	25.0	5.3	0.9	2.9	0.9	2.0	15.8	18.1	4.1	2.0	0.3	0.0	2.6	0.6	0.9	1.1	2.6	4.4	4.4	1.1	0.6	4.4
73	27.4	5.4	0.6	0.9	0.0	1.8	18.7	10.8	4.2	3.9	0.0	0.9	2.4	0.6	1.2	0.6	3.9	7.8	2.4	0.9	2.4	3.2
74	25.2	5.3	1.1	1.7	0.8	1.7	12.4	10.7	5.1	5.3	0.8	0.8	4.0	0.8	0.0	0.8	3.4	7.9	2.3	1.1	1.7	7.1
75	25.2	8.3	1.5	4.1	0.0	0.9	17.5	13.7	1.8	2.7	0.6	0.6	2.7	0.6	0.0	0.3	4.4	7.4	1.8	0.3	1.8	3.8
76	31.9	5.4	1.8	2.1	0.9	0.3	23.7	7.0	1.5	4.2	0.0	1.5	1.5	0.3	0.6	0.3	2.1	4.8	5.4	0.6	0.6	3.5
77	30.1	2.7	0.3	1.2	0.6	1.5	21.2	10.6	2.7	3.6	0.3	0.6	2.1	0.6	0.9	0.6	2.7	8.8	2.4	1.5	1.8	3.2
78	26.4	5.6	1.8	1.2	0.0	0.6	23.1	13.0	2.1	3.0	0.9	1.5	2.7	1.2	0.3	0.6	5.6	4.7	3.2	0.9	0.0	1.6
79	26.4	5.1	2.4	0.9	2.7	0.0	12.3	9.0	3.0	6.6	0.9	0.6	3.6	0.9	0.3	0.3	4.2	7.5	6.6	2.4	1.5	2.8
80	22.4	4.9	3.4	2.4	0.0	1.8	20.5	13.8	5.2	2.1	1.2	0.3	2.7	0.0	0.0	1.2	3.4	6.1	2.1	1.2	0.9	4.4
81	17.7	4.0	2.2	0.6	0.9	0.3	20.2	10.8	8.0	5.3	0.0	1.2	2.8	0.9	0.6	0.6	1.2	12.4	5.3	0.6	0.9	3.5
85	23.2	5.5	2.4	0.9	0.3	2.7	18.3	13.7	5.8	3.6	0.6	0.6	2.1	2.7	0.3	0.6	3.6	8.2	1.5	0.9	0.0	2.5
86	21.9	3.8	0.9	0.9	0.6	1.4	17.5	11.4	5.8	3.8	2.9	1.4	2.6	0.9	0.0	0.9	2.6	8.5	5.6	2.0	1.4	3.0
87	25.7	5.3	1.9	2.5	1.9	0.9	15.3	10.3	4.7	4.4	2.5	0.6	3.7	0.9	0.0	0.6	3.1	3.7	5.3	3.7	0.3	2.7
88	22.3	5.4	2.6	1.4	3.1	0.9	17.2	10.6	4.6	2.6	3.7	0.3	1.5	0.9	0.3	1.1	3.7	4.3	3.7	3.1	1.1	5.6
89	29.1	4.0	5.5	0.3	1.8	0.9	15.6	8.3	6.1	0.9	3.1	0.9	1.5	0.0	0.3	0.0	6.1	3.4	2.4	2.7	1.5	5.6
90	25.3	6.7	5.0	0.9	2.0	0.6	13.5	10.8	7.3	1.7	1.4	0.6	1.2	0.6	0.6	0.0	4.4	7.3	3.5	2.6	0.9	3.1
92	27.1	7.5	3.2	0.9	1.7	2.6	15.0	10.0	5.4	2.3	1.4	0.6	0.9	0.6	0.6	0.3	4.9	3.2	4.1	2.0	1.1	4.6
93	17.0	1.7	2.0	0.6	2.9	1.1	25.8	6.9	6.6	2.3	3.7	2.3	4.0	0.3	0.6	0.3	3.4	3.7	5.2	4.0	1.1	4.5
94	34.4	4.3	2.9	0.9	1.1	0.6	15.7	6.0	6.0	0.0	4.0	1.1	2.0	0.6	1.4	0.0	3.4	4.9	2.3	3.4	0.9	4.1
95	32.5	5.0	1.2	0.0	5.0	0.0	16.8	7.8	4.4	0.3	5.0	1.8	2.5	0.3	0.3	0.0	3.7	2.2	4.0	2.8	0.9	3.5
97	31.6	5.7	1.2	1.2	2.1	0.6	15.3	6.6	4.8	1.8	4.5	2.1	3.0	0.3	0.0	0.0	4.5	3.6	4.2	2.1	0.3	4.5
98	36.3	2.7	2.1	0.3	5.4	0.9	14.5	6.3	2.4	2.4	6.0	1.2	1.8	0.9	0.3	0.3	2.4	5.1	3.3	1.2	1.5	2.7
99	34.5	2.7	4.7	1.8	2.7	0.6	15.1	7.7	3.6	2.1	3.6	0.6	1.8	0.6	0.6	0.0	3.0	7.4	2.4	0.3	0.3	3.9
100	33.5	1.5	1.8	0.9	3.3	0.3	24.2	3.0	3.0	1.8	4.5	0.6	2.1	0.9	0.3	0.6	3.8	7.8	1.2	0.9	0.6	4.2
101	33.4	6.0	4.8	0.9	4.8	0.6	18.0	4.8	4.8	1.5	1.5	0.6	1.2	0.0	0.3	0.3	3.9	4.5	3.3	0.9	0.0	3.9
102	45.0	3.6	3.0	0.6	2.7	1.2	15.7	2.7	5.6	0.9	1.5	0.0	2.1	0.3	0.0	0.3	5.3	3.9	1.5	0.0	0.9	3.2
103	43.3	2.8	2.3	0.3	4.2	0.3	17.5	3.7	2.8	1.4	0.6	0.0	1.4	0.3	0.0	0.0	4.5	3.4	5.4	0.9	0.9	4.0
104	21.0	1.5	0.3	0.0	0.6	1.3	23.5	9.7	2.5	1.9	1.3	1.9	0.6	0.3	0.0	0.0	3.7	9.4	18.0	0.9	0.0	0.7
108	21.2	3.6	0.3	0.3	0.9	0.9	31.2	7.9	3.6	3.0	1.2	0.9	0.6	1.2	0.0	0.6	5.7	9.4	3.9	1.8	0.3	1.5
109	16.6	3.1	1.2	0.3	0.6	0.3	16.9	11.4	0.9	1.5	1.5	0.9	1.2	0.6	0.6	0.3	8.6	16.3	12.0	0.9	0.6	3.7
113	20.4	3.0	0.3	0.3	0.6	0.3	23.6	13.4	1.2	2.1	0.9	0.9	2.1	0.9	0.6	0.3	5.9	10.3	5.6	2.4	1.2	3.7
115	18.7	4.0	1.8	0.9	0.9	0.6	29.0	11.5	4.6	3.1	3.7	0.9	2.2	0.6	0.9	0.3	2.2	5.0	2.2	2.8	1.2	2.9
116	19.8	5.4	1.5	1.2	3.3	0.9	27.4	8.4	2.1	4.2	3.3	0.9	2.4	0.6	1.5	0.6	3.6	3.0	2.1	2.1	1.2	4.5
117	19.4	3.6	0.6	1.2	1.2	1.2	19.1	7.8	2.4	2.7	3.0	3.6	0.6	1.2	0.0	0.6	8.4	10.1	3.9	4.5	0.6	4.3

Station	Aluminium	Boron	Barium	Calcium	Cobalt	Chromium	Copper	Iron	Gallium	Potassium	Magnesium	Manganese	Sodium	Nickel	Lead	Scandium	Strontium	Titanium	Vanadium	Zirconium
	Chemical Elements, Spectrographic																			
58	2.5	61	80	1.95	5.1	58	8.4	2.19	2.8	0.39	0.34	445	0.37	15.7	11	7.1	94	2700	52	930
59	2.7	50	64	2.25	4.4	67	6.0	2.20	2.7	0.44	0.40	505	0.35	13.5	11	6.7	106	3450	54	770
60	2.9	51	103	2.55	4.9	73	9.3	2.32	3.2	0.42	0.40	460	0.36	16.4	15	6.5	118	2980	55	560
61	2.5	50	138	2.05	4.6	118	11.0	2.68	3.2	0.42	0.31	465	0.39	28.0	13	9.5	118	3700	59	2500
62	7.7	50	150	3.25	9.7	67	66.0	3.90	9.9	0.66	0.49	815	0.96	29.0	66	12.0	146	2530	68	150
63	3.3	36	110	2.38	5.2	31	9.5	1.89	3.2	0.43	0.35	510	0.42	12.6	30	4.7	124	1850	42	255
64	3.1	29	35	2.38	4.9	19	5.9	1.88	1.3	0.24	0.35	450	0.25	13.1	15	4.4	118	1030	42	140
65	3.4	50	85	2.61	4.8	59	15.4	2.05	2.9	0.38	0.37	435	0.40	14.3	20	6.4	123	3100	47	430
66	2.9	67	90	2.17	5.9	117	14.0	2.88	3.5	0.39	0.29	600	0.44	23.9	30	9.6	113	4400	66	2200
67	3.8	92	225	2.52	6.7	515	11.0	5.95	4.2	0.43	0.39	1130	0.40	135.0	18	32.0	215	11000	136	7700
68	3.0	48	90	2.59	4.6	55	13.1	2.05	2.9	0.43	0.36	420	0.45	13.6	17	5.3	116	2100	49	230
69	3.8	45	96	2.80	5.0	46	5.3	2.03	3.0	0.36	0.40	465	0.33	14.3	16	7.0	124	2550	48	480
71	4.6	38	10	3.90	6.0	42	8.9	2.60	4.2	0.37	0.39	540	0.48	16.1	15	6.6	166	1600	53	187
72	2.8	61	120	2.24	4.9	85	6.6	2.50	2.6	0.34	0.39	500	0.37	17.8	15	8.5	108	4200	59	1440
73	3.2	33	30	2.57	4.1	35	5.6	1.42	1.9	0.27	0.37	420	0.29	9.8	13	4.3	118	1600	38	227
74	3.0	65	210	2.05	4.5	190	5.9	3.60	3.2	0.46	0.34	700	0.35	50.0	13	17.7	133	4700	76	4200
75	2.7	53	110	2.11	4.5	44	5.6	1.98	2.5	0.41	0.35	460	0.37	14.3	15	7.1	94	2800	52	980
76	2.8	49	120	2.05	4.7	71	2.4	2.34	2.7	0.41	0.36	510	0.39	15.8	14	6.7	93	2650	54	800
77	2.9	34	75	2.05	4.4	62	2.9	1.88	2.5	0.43	0.39	380	0.34	13.5	14	4.3	95	1400	45	130
78	2.8	40	55	2.00	4.3	23	2.6	1.86	2.5	0.38	0.35	420	0.29	10.7	10	5.3	82	1900	45	176
79	3.6	27	60	3.12	5.4	41	9.8	2.26	3.4	0.41	0.43	450	0.40	12.7	17	4.6	170	1300	57	94
80	2.7	26	20	2.30	5.0	18	5.7	1.84	2.3	0.28	0.36	360	0.27	14.1	12	4.3	110	1150	48	60
81	3.0	31	40	1.78	5.8	36	3.4	2.31	2.6	0.35	0.30	560	0.35	14.6	22	6.1	81	2000	59	510
85	3.4	41	25	2.38	5.7	55	4.6	2.40	3.2	0.30	0.37	560	0.36	14.5	30	6.0	106	1900	60	320
86	3.2	28	20	2.00	6.2	20	2.8	2.03	2.7	0.31	0.33	590	0.26	12.5	21	4.4	92	1140	56	96
87	3.7	28	100	2.27	7.5	34	3.5	2.51	3.4	0.42	0.35	740	0.40	15.5	24	5.7	110	1600	59	123
88	3.1	31	120	2.10	6.1	30	3.7	2.15	2.8	0.42	0.34	540	0.27	13.0	19	5.0	104	1450	53	148
89	3.2	56	120	2.28	5.5	45	3.4	2.20	3.2	0.48	0.40	520	0.31	13.5	16	5.9	105	2550	55	149
90	3.4	32	100	2.12	5.9	27	3.2	2.10	3.2	0.43	0.36	570	0.38	13.7	20	5.0	104	1730	51	165
92	3.2	37	70	2.23	5.0	27	3.1	1.95	3.0	0.44	0.37	455	0.40	14.5	13	5.9	105	2400	50	410
93	3.5	58	200	2.19	5.8	95	5.6	2.76	3.9	0.52	0.37	560	0.49	18.9	26	9.8	108	4850	66	1300
94	4.2	38	105	2.97	4.6	48	3.3	2.19	2.8	0.31	0.42	440	0.35	20.4	12	8.4	150	3000	52	1640
95	3.6	28	100	2.80	5.7	38	4.0	2.18	3.0	0.35	0.35	460	0.43	14.2	29	6.3	143	2120	50	700
97	5.9	34	160	3.40	6.4	47	4.7	2.95	5.4	0.51	0.38	530	0.45	18.8	27	8.2	160	2500	62	165
98	4.0	31	170	2.78	5.3	32	3.6	2.33	3.4	0.38	0.33	430	0.43	16.3	21	5.6	152	1560	53	200
99	3.6	39	65	2.85	4.8	53	2.7	2.25	2.9	0.31	0.40	475	0.30	13.0	9	5.4	110	1920	53	220
100	3.6	35	130	2.49	4.8	23	3.0	2.05	2.9	0.34	0.38	420	0.34	12.2	9	4.9	118	1480	47	88
101	3.5	63	200	2.35	4.7	83	3.4	2.71	3.0	0.36	0.40	640	0.36	16.4	11	7.7	115	4000	58	372
102	3.8	43	205	2.35	5.1	92	4.1	2.55	4.3	0.55	0.31	550	0.49	18.6	26	8.1	120	3400	52	1490
103	3.7	50	200	2.52	6.2	170	4.4	3.10	4.2	0.50	0.34	670	0.53	27.4	36	11.7	125	4800	62	2000
104	8.9	36	270	4.00	9.2	50	12.0	4.35	7.9	0.67	0.46	400	0.62	30.0	34	12.4	153	2700	68	152
108	4.4	28	130	2.90	6.5	28	4.9	2.92	4.4	0.45	0.35	335	0.43	17.5	16	7.0	128	1700	51	218
109	14.8	44	260	2.73	14.7	69	27.0	6.20	17.6	1.00	1.06	465	1.03	42.5	18	27.5	163	4000	92	155
113	9.2	40	300	4.10	10.1	59	15.0	4.52	11.5	0.80	0.95	540	0.82	30.0	24	15.4	197	2200	57	124
115	3.2	43	170	2.42	5.0	41	7.7	2.39	2.8	0.33	0.34	460	0.35	13.0	15	5.0	122	2000	54	270
116	3.4	49	220	2.59	5.2	100	16.9	3.10	3.3	0.33	0.38	560	0.42	21.0	18	9.6	115	4100	70	1610
117	5.9	32	160	4.00	8.0	46	15.5	3.40	5.5	0.59	0.53	580	0.70	25.0	21	8.3	180	1820	66	245

TABLE V

(St. 118–163)

Station	Depth	Textural Statistics: Q1	Q3	Md	So	Sk	Ø16	Ø50	Ø84	ØMz	Øσg	ØMI	Basic X-ray Diffractogram Values: Mica	Chlorite	Quartz	Orthoclase	Plagioclase	Calcite	Dolomite	Background	X-ray Mineral Percentages: Mica	Chlorite	Quartz	Orthoclase	Plagioclase	Calcite	Dolomite	Phyllosilicates	Feldspars	Carbonates
118	11.0	0.26	0.20	0.23	1.14	0.98	1.9	2.1	2.5	2.2	0.30	2.2	3	4	73	4	7	9	3	13	3	2	81	2	5	6	1	5	7	7
119	0	0.22	0.18	0.19	1.10	1.10	1.9	2.4	2.6	2.3	0.35	2.2	2	6	79	5	6	4	3	14	2	3	85	3	4	2	1	5	7	3
120	0	0.30	0.19	0.24	1.26	0.99	1.4	2.1	2.6	2.0	0.60	2.0	3	8	77	7	9	6	2	14	3	4	80	4	5	3	1	7	9	4
121	0	0.25	0.18	0.21	1.18	1.02	1.9	2.3	2.6	2.3	0.35	2.2	3	7	71	6	7	5	2	14	3	5	80	3	5	3	1	8	8	4
122	0	0.24	0.19	0.22	1.12	0.94	1.9	2.2	2.4	2.2	0.25	2.1	2	6	78	3	6	4	2	14	2	3	86	2	4	2	1	5	6	3
123	0	0.14	0.09	0.11	1.14	1.04	2.5	3.2	3.5	3.1	0.50	3.0	3	7	77	5	7	4	1	14	3	4	82	3	5	2	1	7	8	3
124	0	0.07	0.05	0.06	1.20	0.96	3.7	4.1	4.5	4.1	0.40	4.1	7	23	37	2	8	10	3	20	11	18	55	2	6	7	1	29	8	8
125	0	0.16	0.14	0.15	1.07	0.99	2.6	2.7	3.1	2.8	0.25	2.8	3	8	69	6	7	5	2	15	4	5	79	3	5	3	1	9	8	4
126	0	0.07	0.05	0.06	1.15	0.99	3.7	4.1	4.4	4.1	0.35	4.0	6	22	51	5	13	8	4	20	7	13	62	4	8	5	1	20	12	6
127	0	0.15	0.12	0.13	1.12	1.06	2.7	2.9	3.2	2.9	0.30	2.9	3	9	75	6	12	2	2	17	3	5	80	3	7	1	1	8	10	2
128	0	0.14	0.10	0.12	1.18	0.97	2.7	3.1	3.6	3.1	0.45	3.1	4	15	65	6	12	2	2	19	5	9	74	3	7	1	1	14	10	2
129	0	0.15	0.11	0.13	1.17	0.97	2.6	3.1	3.4	3.0	0.40	3.0	3	12	71	6	12	2	2	18	3	7	78	3	7	1	1	10	10	2
130	0	1.6	0.15	0.36	3.25	1.85	-1.3	1.5	3.1	1.1	2.20	0.9	11	31	52	3	9	0	0	22	13	19	60	2	6	0	0	32	8	0
131	0	5.6	0.44	0.84	3.56	3.49	-3.0	0.2	1.7	-1.1	2.35	0.6	6	20	51	2	13	6	2	20	8	13	65	1	8	4	1	21	9	5
132	0	0.18	0.16	0.17	1.06	0.99	2.3	2.6	2.7	2.5	0.20	2.5	4	8	77	7	7	4	2	16	4	4	81	4	4	2	1	8	8	3
133	0	0.21	0.18	0.19	1.08	1.04	2.1	2.4	2.6	2.4	0.25	2.3	2	6	79	3	5	4	2	14	2	4	86	2	3	2	1	6	5	3
134	0	0.20	0.18	0.19	1.05	0.99	2.1	2.4	2.6	2.4	0.25	2.3	2	6	83	4	5	3	1	14	2	3	87	2	3	2	1	5	5	3
135	0	0.16	0.14	0.15	1.07	0.99	2.5	2.7	2.9	2.7	0.20	2.7	2	7	74	3	6	7	3	15	2	5	82	2	3	5	1	7	5	6
136	0	0.14	0.10	0.12	1.18	0.97	2.7	3.1	3.6	3.1	0.45	3.1	5	18	55	4	14	9	2	14	6	11	66	2	8	6	1	17	10	7
137	0	1.40	0.39	0.56	1.94	1.74	-2.3	0.7	1.6	-0.1	1.95	-0.3	11	35	28	3	29	0	0	26	15	24	38	3	20	0	0	39	23	0
138	0	8.4	2.0	4.8	2.25	0.73	-3.3	-2.3	-0.5	-2.0	1.40	-1.9	17	37	33	0	12	0	0	26	23	25	44	0	8	0	0	48	8	0
139	0	0.14	0.12	0.13	1.08	0.99	2.7	2.9	3.2	2.9	0.25	2.9	3	11	70	8	14	1	3	16	3	7	76	4	8	1	1	10	12	2
140	0	0.14	0.08	0.11	1.32	0.92	2.7	3.2	4.0	3.3	0.65	3.3	4	17	57	3	11	9	3	18	5	11	68	2	7	6	1	16	9	7
141	0	0.17	0.14	0.16	1.10	0.93	2.6	2.7	2.9	2.7	0.15	2.7	3	8	67	5	9	9	0	16	3	5	77	3	6	6	0	8	9	6
142	0	0.18	0.16	0.17	1.06	0.99	2.3	2.6	2.7	2.5	0.20	2.5	3	8	75	5	8	5	2	15	3	5	81	3	4	3	1	8	7	4
143	0	0.32	0.27	0.29	1.08	1.02	1.6	1.8	2.0	1.8	0.20	1.8	2	6	81	2	5	3	1	15	2	4	87	1	3	2	1	6	4	3
144	0	3.3	0.86	1.6	1.96	1.11	-2.3	-0.7	0.5	-0.8	1.40	-0.9	8	27	53	0	10	3	0	20	10	17	65	0	6	2	0	27	6	2
145	0	0.07	0.05	0.06	1.16	0.97	3.7	4.0	4.4	4.0	0.35	4.0	4	22	56	2	7	7	2	20	5	14	69	1	5	5	1	19	6	6
146	0	1.5	0.49	0.82	1.75	1.09	-0.9	0.3	1.4	0.3	1.15	0.2	4	14	60	3	10	8	1	17	5	9	72	2	6	5	1	14	8	6
147	0	0.27	0.22	0.25	1.11	0.95	1.7	2.0	2.3	2.0	0.30	2.0	3	7	81	4	9	5	2	15	3	4	82	2	5	3	1	7	7	4
148	0	2.0	0.70	1.11	1.69	1.13	-1.9	-0.1	0.8	-0.4	1.35	-0.5	11	42	45	2	13	2	2	22	13	24	52	1	8	1	1	37	9	2
149	0	2.5	0.94	1.5	1.63	1.04	-1.7	-0.6	0.3	-0.6	1.00	-0.7	13	46	47	2	14	2	2	23	14	25	50	1	8	1	1	39	9	2
150	0	0.33	0.22	0.27	1.22	0.99	1.4	1.9	2.3	1.9	0.45	1.8	5	15	66	1	4	7	4	17	6	9	75	1	2	5	2	15	3	7
151	0	0.30	0.23	0.27	1.14	0.94	1.6	1.9	2.3	1.9	0.35	1.9	3	11	72	3	5	7	2	15	4	7	79	2	3	4	1	11	5	5
152	0	0.28	0.19	0.23	1.22	1.00	1.6	2.1	2.6	2.1	0.50	2.1	3	10	74	4	6	8	2	15	3	6	81	2	3	4	1	9	5	5
153	0	0.29	0.22	0.25	1.15	1.02	1.5	2.0	2.3	1.9	0.40	1.9	3	8	79	5	6	6	2	15	3	4	83	3	3	3	1	7	6	4
154	0	0.24	0.17	0.20	1.18	1.02	1.9	2.3	2.7	2.3	0.40	2.3	2	9	78	4	7	6	2	15	2	5	83	2	4	3	1	7	6	4
155	0	4.9	1.8	2.9	1.65	1.05	-2.6	-1.5	-0.6	-1.5	1.00	-1.6	21	46	33	3	9	0	0	27	25	27	39	3	6	0	0	52	9	0
156	0	4.7	0.74	2.1	2.52	0.79	-2.7	-1.1	1.3	-0.8	2.00	-0.7	19	50	35	3	10	0	0	26	22	29	41	2	6	0	0	51	8	0
157	0	0.07	0.06	0.07	1.13	0.98	3.6	3.9	4.2	3.9	0.30	3.9	6	24	52	2	9	12	2	20	7	15	63	1	6	7	1	22	7	8
158	0	0.15	0.13	0.14	1.07	0.99	2.6	2.8	3.1	2.8	0.25	2.8	5	15	62	6	11	10	2	16	6	9	69	3	6	6	1	15	9	7
158-A	0	0.19	0.15	0.17	1.08	0.98	2.3	2.6	2.7	2.5	0.20	2.5	2	6	81	4	7	4	2	16	2	3	86	2	4	2	1	5	6	3
159	0	0.19	0.08	0.11	1.54	1.25	2.1	3.2	3.8	3.0	0.85	2.9	11	39	52	6	13	2	2	22	12	21	55	3	7	1	1	33	10	2
160	0	0.16	0.11	0.13	1.20	1.04	2.5	2.9	3.5	2.9	0.50	3.0	14	58	32	2	12	0	0	28	17	35	39	2	7	0	0	52	9	0
161	0	0.48	0.33	0.35	1.20	1.29	-2.4	1.5	1.7	0.2	2.05	0.3	20	61	31	3	11	0	0	27	22	35	34	2	7	0	0	57	9	0
162	0	9.8	2.5	5.4	1.98	0.84	-3.5	-2.4	-0.9	-2.3	1.30	2.2	19	58	31	2	8	0	0	27	23	34	37	1	5	0	0	57	6	0
163	0	0.15	0.12	0.13	1.12	1.06	2.7	2.9	3.2	2.9	0.25	2.9	5	15	70	8	13	1	2	18	5	9	73	4	7	1	1	14	11	2

Station	Optical Petrography, Grain Types, Percentages: Quartz 1	Quartz 2	Quartz 3	Quartz 4	Quartz 5	Quartz 6	Quartz 7	Quartz 8	Quartz 9	Quartz 10	Quartz 11	Quartz 12	Quartz 13	Quartz 14	Quartz 15	Quartz 16	Carbonates	Arenites	Shale-slate	Crystallines	Chert	Feldspars
118	23.7	4.4	1.9	0.9	3.5	0.9	22.1	9.5	3.5	2.8	3.8	2.2	2.2	0.9	0.9	0.6	2.2	7.3	1.6	1.6	0.9	2.6
119	33.2	2.7	0.9	0.9	1.2	0.6	25.3	6.3	1.5	3.9	2.7	1.8	2.1	0.0	2.1	0.9	1.2	5.3	2.1	1.5	0.9	2.9
120	33.7	2.1	0.9	0.3	2.8	1.5	20.4	7.1	1.5	2.8	3.7	1.8	0.6	0.3	1.2	0.3	1.8	5.9	3.4	4.6	0.6	2.7
121	25.0	3.1	0.9	0.6	3.1	1.5	25.0	8.3	4.3	1.5	5.8	1.2	2.1	0.0	0.6	1.2	1.8	5.8	3.1	2.1	1.5	1.5
122	34.6	3.1	2.2	0.9	2.2	1.9	18.3	6.6	3.2	2.2	2.5	0.9	2.5	0.3	0.9	0.9	1.2	6.6	2.8	3.2	0.3	2.7
123	26.1	2.4	0.3	0.6	1.8	2.7	28.8	7.9	4.5	4.0	4.0	1.2	0.9	0.3	2.1	1.5	1.5	3.6	2.7	1.8	0.3	1.0
124	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
125	23.2	2.1	3.7	0.3	1.8	1.8	21.4	7.3	3.4	0.9	3.4	2.8	1.5	0.0	3.3	0.6	0.6	9.8	4.0	1.8	0.9	5.4
126	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
127	19.0	4.6	3.0	3.3	3.3	4.9	10.8	9.8	5.2	4.0	0.0	0.3	3.6	0.3	0.3	0.3	1.0	7.9	10.8	3.0	2.3	2.3
128	38.7	2.8	0.9	0.3	0.6	0.3	16.8	7.8	3.7	0.6	1.9	0.0	0.0	0.3	2.8	0.0	0.0	7.2	8.7	2.5	0.6	3.5
129	25.7	0.9	0.0	0.3	1.2	1.8	20.5	5.2	4.6	0.9	2.1	2.1	1.5	0.3	3.0	1.9	0.0	18.7	4.3	0.6	0.0	4.4
130	35.6	5.8	1.8	1.2	1.5	1.2	8.3	6.8	1.5	2.8	3.1	0.9	0.6	0.3	0.0	0.0	0.0	9.5	14.4	1.5	0.0	3.2
131	28.4	2.2	0.6	0.6	1.8	4.6	13.0	7.1	2.5	1.2	3.1	2.8	1.2	0.3	1.8	1.2	3.4	5.6	6.5	7.4	0.3	4.4
132	30.2	2.6	0.6	0.0	3.5	0.9	22.0	5.5	4.0	0.9	6.1	0.9	1.4	0.0	2.9	0.9	0.0	4.0	4.6	4.9	0.3	5.1
133	30.8	5.5	4.6	0.6	4.2	1.2	7.3	7.9	7.6	1.5	3.4	0.3	1.5	0.0	2.4	2.7	0.3	6.1	2.7	4.2	0.0	5.2
134	28.5	2.8	2.2	0.3	3.1	0.6	18.4	9.1	3.1	1.8	5.6	0.6	1.2	0.6	1.5	0.9	0.6	2.5	4.1	8.4	0.0	4.1
135	33.2	3.0	0.9	0.9	4.5	0.3	19.3	4.8	2.1	1.2	3.0	0.9	1.8	0.3	3.0	0.6	0.9	8.1	4.8	2.7	0.6	3.1
136	33.1	3.5	1.9	0.0	1.9	0.0	15.1	3.2	1.3	0.6	1.0	0.0	0.3	0.0	4.8	0.0	2.3	11.5	13.8	1.9	0.6	3.2
137	1.0	0.0	0.0	0.0	3.2	2.8	4.4	0.6	0.3	0.6	2.8	2.5	0.6	0.0	7.9	0.0	0.0	17.0	23.4	28.5	0.0	4.3
138	0.0	0.0	0.0	0.0	3.9	2.4	0.0	0.0	0.8	0.8	2.4	0.0	0.0	0.0	0.0	0.0	0.0	31.5	37.7	18.7	0.8	1.0
139	28.2	2.4	0.9	0.0	2.7	0.6	29.5	6.1	4.0	1.2	1.5	0.3	0.3	0.0	4.8	0.3	0.3	4.9	6.1	4.0	0.6	1.3
140	31.5	1.3	3.8	0.0	0.3	0.0	21.2	7.2	4.7	1.6	1.3	0.3	1.6	0.3	3.1	0.0	1.6	9.3	5.9	0.9	0.6	3.5
141	31.1	2.1	0.9	1.2	2.7	0.9	14.8	8.6	3.8	0.9	3.0	0.6	1.5	0.0	3.6	0.6	3.3	11.0	4.5	0.6	0.3	4.0
142	30.9	7.6	1.5	0.6	3.7	0.9	11.6	6.7	2.8	0.9	1.8	2.1	1.2	0.9	2.1	0.6	2.1	6.7	6.4	3.3	1.5	4.1
143	24.8	2.7	0.9	2.7	0.9	0.6	21.2	7.3	3.0	4.8	3.3	1.5	0.9	1.2	1.2	0.6	1.8	8.8	5.4	2.4	0.6	3.6
144	14.7	1.5	0.3	0.6	1.5	1.8	17.4	6.3	0.9	4.5	0.6	2.7	0.6	0.6	2.1	0.6	4.5	24.9	10.8	1.5	0.6	1.0
145	32.4	5.1	1.2	0.0	0.3	0.3	26.4	10.6	5.1	3.0	0.9	1.2	3.0	0.6	0.9	0.0	0.9	3.9	0.6	0.0	0.0	3.6
146	12.3	0.9	0.6	0.0	1.2	0.6	15.7	8.6	2.8	4.3	2.4	2.4	0.3	0.6	0.3	0.0	8.9	26.8	5.8	2.1	1.5	1.9
147	19.4	2.2	0.0	0.3	1.5	0.3	32.5	12.8	4.4	1.2	3.7	3.2	0.3	0.6	4.0	0.9	0.3	7.8	0.0	1.5	0.3	3.8
148	2.9	0.0	0.0	0.0	0.3	0.0	14.6	3.2	0.6	1.0	5.7	3.2	0.6	0.3	0.3	0.3	1.5	38.7	22.2	1.2	0.0	3.4
149	1.5	0.0	0.0	0.0	0.4	0.7	9.0	1.9	0.7	1.5	4.2	2.6	0.8	0.0	0.0	0.0	5.3	45.6	21.0	2.2	0.0	2.6
150	10.6	0.6	0.9	0.0	1.8	0.3	31.1	15.5	3.4	1.5	5.6	2.5	0.6	0.6	1.5	0.0	1.8	10.0	4.7	2.8	0.0	4.2
151	14.8	0.6	1.2	0.0	0.9	0.3	23.8	16.6	7.4	2.1	4.2	1.2	0.3	0.3	0.9	0.0	1.5	10.7	7.7	1.2	1.2	3.0
152	23.2	1.8	0.9	0.0	0.6	0.0	29.5	11.2	2.8	0.6	3.4	0.6	0.3	0.3	1.2	0.3	3.7	10.5	5.6	0.3	0.3	2.9
153	20.4	2.5	1.2	0.6	0.3	0.0	29.1	8.8	4.0	1.6	4.0	0.3	0.0	0.0	1.2	0.3	1.9	10.0	7.2	2.2	0.6	3.8
154	21.3	2.5	2.5	0.0	2.2	0.3	23.0	9.4	5.0	1.9	3.9	1.1	0.9	0.3	1.2	0.0	3.3	13.8	4.2	0.8	0.0	2.4
155	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.6	1.9	0.0	0.0	0.0	0.0	0.0	0.0	21.6	74.1	0.6	0.0	0.6
156	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	18.4	72.6	0.0	0.0	5.2
157	41.5	5.2	3.0	0.0	0.7	0.0	32.6	5.9	3.7	0.0	0.0	0.0	0.0	0.7	0.0	0.0	2.2	0.7	3.0	0.0	0.0	0.8
158	14.9	5.5	2.3	1.3	1.0	1.3	8.1	12.6	2.3	6.8	0.6	0.0	2.9	0.0	0.0	0.3	2.3	20.4	10.0	0.0	2.3	5.1
158-A	32.4	1.5	3.5	0.0	1.5	0.9	17.5	5.8	7.0	2.6	1.7	1.5	2.0	0.3	0.9	0.3	2.6	8.5	3.2	0.6	0.3	5.4
159	38.0	2.0	0.7	0.0	0.7	0.0	17.6	3.3	2.0	1.0	1.3	0.0	0.3	0.3	0.3	0.0	0.6	7.0	24.2	0.0	0.0	0.7
160	1.3	0.6	0.3	0.0	0.0	0.0	2.2	0.3	4.2	0.0	0.6	0.6	0.0	0.0	0.3	0.0	0.0	9.7	79.5	0.0	0.0	0.4
161	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.6	0.6	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	6.0	91.0	0.0	0.0	0.3
162	0.0	0.0	0.0	0.0	0.6	0.0	0.3	0.3	0.3	0.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0	6.1	91.2	0.0	0.0	0.0
163	27.5	3.3	3.6	1.0	0.7	0.3	13.6	5.6	5.6	1.6	2.0	0.3	0.0	0.3	0.3	0.0	0.0	7.6	25.9	0.0	0.0	0.8

Station	Chemical Elements, Spectrographic: Aluminium	Boron	Barium	Calcium	Cobalt	Chromium	Copper	Iron	Gallium	Potassium	Magnesium	Manganese	Sodium	Nickel	Lead	Scandium	Strontium	Titanium	Vanadium	Zirconium
118	3.1	42	75	2.75	5.0	31	7.0	1.95	2.4	0.31	0.42	440	0.32	11.7	8	4.6	132	1470	50	145
119	2.8	27	75	1.32	4.5	18	2.6	1.67	2.3	0.32	0.27	275	0.32	10.3	5	4.6	93	1420	39	90
120	3.1	23	90	1.96	5.0	21	2.4	1.79	3.4	0.41	0.27	300	0.47	12.8	6	4.9	114	1100	35	81
121	3.4	30	110	1.82	5.2	37	3.3	2.16	3.4	0.39	0.31	365	0.44	15.9	10	7.0	100	2450	47	890
122	2.6	24	60	1.34	4.4	20	2.8	1.85	2.1	0.33	0.26	295	0.30	11.4	5	5.1	92	1780	41	210
123	3.1	21	50	1.38	4.4	19	3.5	1.92	2.1	0.32	0.26	270	0.31	15.0	5	5.3	88	1330	38	82
124	9.8	59	410	3.10	11.8	73	57.0	4.05	14.5	1.68	1.06	430	1.50	36.5	108	17.8	158	3750	68	305
125	3.6	35	125	1.26	6.2	31	10.6	2.30	3.9	0.51	0.32	286	0.44	16.3	11	6.3	92	1850	48	102
126	10.8	53	240	2.20	10.9	91	59.0	4.02	12.2	0.96	1.18	575	0.95	37.0	57	19.9	116	4800	76	1100
127	4.0	28	185	0.66	7.2	30	14.2	2.35	4.7	0.70	0.36	265	0.56	18.6	13	6.7	80	2300	49	180
128	5.4	40	135	0.66	11.4	52	56.0	3.91	7.8	0.89	0.45	490	0.74	27.5	39	10.6	81	2150	67	275
129	3.7	40	185	0.66	8.7	66	30.0	3.15	5.9	0.74	0.37	345	0.61	25.4	21	10.4	100	3500	61	890
130	11.7	41	385	0.14	5.4	66	10.6	4.20	13.5	1.18	0.66	305	0.77	28.0	8	18.5	89	4600	82	255
131	8.8	29	395	3.65	10.8	57	12.5	4.40	11.1	0.76	0.56	1170	0.80	26.0	22	18.5	200	3330	75	141
132	3.2	27	55	1.58	4.8	40	3.5	2.15	2.5	0.38	0.31	305	0.41	14.3	9	5.9	90	1880	45	135
133	2.9	22	75	1.45	4.6	17	3.0	1.89	2.3	0.34	0.28	290	0.35	11.8	7	4.7	77	1350	40	84
134	3.1	28	70	1.60	4.1	25	3.9	1.97	2.3	0.33	0.32	330	0.38	14.5	8	5.4	81	1580	41	139
135	4.8	34	40	1.94	5.2	25	4.7	1.87	3.2	0.49	0.34	310	0.34	13.0	13	6.0	100	2110	47	129
136	8.1	38	200	3.00	7.5	52	[illegible]	3.10	7.8	0.79	0.64	305	0.75	25.4	37	11.6	160	2450	57	215
137	17.0	24	590	0.67	16.3	79	[illegible]	5.90	23.4	2.26	1.45	820	1.50	34.0	82	37.4	118	5850	113	170
138	18.1	34	580	0.26	23.3	88	610.0	6.64	26.0	2.29	1.41	1330	1.10	39.5	72	28.0	86	4050	103	150
139	4.2	34	140	0.57	8.5	33	29.4	2.69	5.2	0.84	0.38	290	0.60	20.5	18	7.4	85	2400	50	125
140	5.1	49	220	2.30	9.4	57	35.0	3.45	6.3	0.76	0.40	400	0.78	27.5	36	12.5	125	3150	60	455
141	4.1	29	170	2.24	7.1	29	7.8	2.37	3.8	0.59	0.28	275	0.46	18.0	13	5.7	110	1650	45	122
142	3.3	32	85	1.87	4.9	21	2.9	1.96	2.4	0.39	0.32	305	0.34	13.0	10	4.8	106	1380	40	108
143	2.5	27	50	1.30	4.4	21	2.3	2.07	2.1	0.24	0.27	320	0.18	10.7	4	5.7	93	1650	43	67
144	9.2	144	220	1.95	11.0	52	16.0	4.52	10.8	0.80	0.46	425	0.76	32.0	39	15.5	95	3000	81	140
145	7.8	60	320	1.76	11.5	70	25.5	4.18	8.9	0.90	0.48	335	0.74	35.0	100	15.6	83	3850	78	460
146	7.1	24	210	6.30	7.2	26	5.1	3.21	5.0	0.46	0.45	450	0.56	19.5	79	5.6	313	1300	45	78
147	2.5	22	40	1.60	4.5	19	2.2	1.66	2.3	0.29	0.26	220	0.31	11.0	12	3.8	78	930	36	91
148	10.8	39	230	2.14	13.4	64	24.7	5.25	14.8	0.96	1.06	480	0.87	36.0	24	16.0	111	3250	72	96
149	10.3	38	250	1.64	12.0	60	26.0	5.00	14.3	1.20	0.93	495	0.96	34.0	32	17.8	106	3200	68	124
150	3.7	39	230	2.05	7.0	75	7.0	3.50	5.2	0.44	0.33	405	0.43	22.0	29	9.2	99	2900	64	263
151	3.0	28	50	2.25	5.9	32	5.0	2.50	3.8	0.35	0.32	310	0.42	17.2	28	6.6	107	1500	46	113
152	3.6	31	140	3.05	4.7	67	14.4	2.44	3.2	0.28	0.34	380	0.24	19.0	20	8.1	152	2870	53	1210
153	3.9	22	55	2.40	4.3	18	2.8	1.95	3.0	0.32	0.32	252	0.30	12.2	19	4.6	122	1370	42	142
154	3.7	30	80	2.16	4.9	25	2.5	2.20	2.6	0.26	0.38	268	0.28	13.3	25	5.2	104	1800	44	107
155	13.2	64	600	0.11	18.3	91	48.0	6.58	23.6	1.73	0.61	212	1.07	47.0	124	25.0	93	4850	101	166
156	14.9	61	540	0.31	14.0	95	63.0	6.70	24.2	1.45	1.22	390	0.97	47.5	118	26.0	96	5400	106	220
157	7.2	47	270	3.20	10.8	56	22.0	4.00	11.8	0.67	0.79	350	0.78	30.7	104	14.2	166	3050	67	175
158	4.2	32	190	2.27	8.2	35	6.2	2.90	6.0	0.54	0.33	260	0.66	21.3	41	6.9	113	2200	52	227
158-A	2.8	45	110	1.36	5.0	37	3.1	2.20	2.7	0.32	0.35	270	0.34	13.3	10	5.6	102	1800	43	125
159	10.1	39	235	0.91	12.2	67	15.6	4.52	14.0	0.90	0.97	495	0.86	35.0	112	14.9	83	3350	65	220
160	16.7	62	380	0.14	24.5	88	59.0	7.30	23.7	1.31	0.95	830	1.08	57.0	277	26.0	82	4550	86	168
161	15.5	68	570	0.09	22.5	99	52.0	8.18	25.5	1.47	1.09	745	1.12	57.5	195	26.7	92	5200	125	110
162	20.4	67	340	0.11	17.4	106	44.5	7.20	25.3	1.59	1.17	800	1.09	53.0	150	33.5	95	5600	108	140
163	4.7	32	230	0.55	10.0	35	12.3	3.30	6.6	0.72	0.44	360	0.66	23.0	50	6.6	86	2200	49	120

TABLE VI
(St. 164–226)

Textural Statistics; Basic X-ray Diffractogram Values

Station	Depth	Q1	Q3	Md	So	Sk	Ø16	ØM50	Ø84	ØMz	Øσg	ØMI	Mica	Chlorite	Quartz	Orthoclase	Plagioclase	Calcite	Dolomite	Background
164	0	3.5	0.76	1.5	1.21	1.18	-2.5	-0.6	0.9	-0.7	1.70	-0.8	23	59	30	4	13	0	0	28
164-A	0	3.3	0.84	1.4	1.98	1.41	-2.7	-0.4	0.6	-0.8	1.65	-1.0	21	60	29	3	9	0	0	26
165	0	0.25	0.21	0.23	1.09	0.99	1.8	2.1	2.4	2.1	0.30	2.1	2	6	75	1	4	5	6	17
166	0	0.30	0.24	0.26	1.26	1.06	1.5	1.9	2.2	1.8	0.35	1.8	1	7	80	1	5	5	1	15
167	0	6.6	0.21	3.0	5.59	0.15	-3.1	-1.6	2.6	-0.7	2.85	-0.2	11	31	49	4	8	6	1	21
168	0	0.25	0.20	0.22	1.11	1.03	1.9	2.2	2.5	2.2	0.30	2.2	1	5	83	5	12	3	2	15
169	0	0.17	0.15	0.16	1.06	0.99	2.5	2.6	2.8	2.6	0.15	2.6	3	11	78	9	11	2	3	17
170	0	0.26	0.19	0.22	1.17	1.02	1.8	2.2	2.6	2.2	0.40	2.2	1	7	83	5	5	4	2	16
171	0	1.10	0.64	0.86	1.32	0.95	-0.4	0.2	0.9	0.2	0.65	0.2	3	15	55	2	9	8	2	18
172	0	0.27	0.20	0.23	1.16	1.02	1.6	2.1	2.5	2.1	0.45	2.0	4	11	76	3	5	3	2	17
173	0	1.1	0.19	0.22	2.41	4.36	-2.3	2.2	2.5	0.8	2.40	0.1	3	10	76	5	8	5	2	17
174	0	0.22	0.17	0.19	1.13	1.03	1.9	2.4	2.7	2.3	0.40	2.4	5	12	80	7	12	6	1	17
175	0	0.31	0.22	0.24	1.19	1.18	1.2	2.1	2.4	1.9	0.60	1.8	2	7	79	9	9	6	3	16
176	0	0.23	0.13	0.18	1.36	0.92	1.9	2.5	3.2	2.5	0.65	2.5	2	9	76	6	7	6	2	17
177	0	0.27	0.20	0.23	1.16	1.02	1.7	2.1	2.5	2.1	0.40	2.1	2	7	80	6	8	5	3	16
178	0	8.6	3.6	5.8	1.54	0.92	-3.3	-2.5	-1.5	-2.4	0.90	-2.4	19	49	38	2	15	0	0	26
179	0	7.2	2.3	4.4	1.77	0.85	-3.1	-2.1	-0.9	-2.0	1.10	-2.0	22	58	31	3	14	0	0	26
180	0	6.6	1.2	2.8	2.34	1.01	-3.2	-1.5	0.1	-1.5	1.65	-1.5	11	41	43	0	16	7	0	24
181	10.5	0.20	0.18	0.19	1.05	0.99	2.2	2.4	2.6	2.4	0.20	2.4	1	3	84	8	5	8	2	15
190	10.5	4.1	0.39	1.2	3.20	1.11	-2.8	-0.3	2.1	-0.3	2.45	-0.3	7	24	31	1	5	25	2	19
191	12.0	3.7	0.35	0.52	3.25	4.78	-2.8	-0.9	1.7	-0.1	2.25	-0.5	7	21	66	2	6	15	2	18
192	12.0	1.4	0.18	0.26	2.70	3.72	-1.6	1.9	2.6	0.9	2.10	0.5	4	12	52	2	5	22	2	17
193	11.5	0.25	0.19	0.21	1.18	1.07	1.8	2.3	2.6	2.2	0.40	2.2	1	3	80	9	6	10	4	16
194	11.5	0.48	0.26	0.31	1.35	1.30	-0.2	1.7	2.1	1.2	1.15	0.9	1	5	74	5	6	12	4	17
195	10.0	0.34	0.22	0.27	1.26	1.02	1.2	1.9	2.4	1.8	0.60	1.8	3	5	71	5	9	11	1	15
196	11.0	3.9	1.5	2.4	1.61	1.01	-2.2	-1.3	-0.3	-1.2	0.95	-1.2	4	18	44	3	19	19	4	20
197	3.0	31.0	22.0	37.0	1.52	0.82	-5.8	-5.2	-8.0	-3.4	3.30	-2.5	2	6	76	4	8	7	1	16
198	6.0	0.29	0.19	0.22	1.23	1.13	1.2	2.2	2.6	2.0	0.70	1.9	3	10	71	6	7	8	1	17
199	6.0	0.21	0.16	0.17	1.14	1.16	2.1	2.6	2.7	2.4	0.30	2.4	1	5	75	9	6	8	2	16
200	10.0	0.47	0.23	0.31	1.42	1.12	0.5	1.7	2.3	1.5	0.90	1.4	4	12	68	4	6	13	1	17
201	11.0	2.3	0.30	0.50	2.76	2.76	-2.5	1.0	2.0	-0.1	2.25	-0.2	4	15	52	1	12	27	3	19
202	10.5	1.2	0.22	0.42	2.33	1.49	-1.6	1.3	2.5	0.7	2.05	0.4	3	8	61	3	9	22	2	17
203	8.5	0.48	0.22	0.31	1.47	1.10	0.8	1.8	2.4	1.6	0.80	1.6	3	8	77	3	6	13	4	18
207	4.0	0.23	0.18	0.20	1.13	1.03	1.9	2.3	2.6	2.2	0.35	2.2	1	5	73	8	6	8	2	17
209	7.0	0.27	0.20	0.24	1.16	0.93	1.7	2.1	2.5	2.1	0.40	2.1	1	3	81	3	3	8	3	16
210	8.0	0.85	0.25	0.43	1.84	1.15	-0.7	1.3	2.4	1.0	1.55	0.8	2	6	68	3	5	9	3	17
215	9.0	30.0	1.4	7.0	4.60	0.85	-5.3	-2.8	0.8	-2.4	3.05	-2.2	9	27	43	1	22	14	2	21
217	6.5	0.25	0.19	0.22	1.14	0.98	1.9	2.2	2.6	2.2	0.35	2.2	1	3	77	5	6	8	5	16
218	6.5	0.31	0.23	0.28	1.16	0.91	1.6	1.8	2.4	1.6	0.35	1.9	1	3	80	2	5	6	2	18
219	5.5	0.19	0.17	0.18	1.05	0.99	2.3	2.5	2.6	2.4	0.15	2.4	1	4	75	11	8	9	3	18
220	5.5	0.19	0.16	0.17	1.09	1.05	2.2	2.6	2.7	2.5	0.25	2.4	1	4	77	5	8	10	3	18
221	4.0	3.6	0.22	0.31	4.04	8.24	-2.4	1.7	2.3	0.5	2.35	-0.1	4	6	72	8	10	6	2	18
222	4.5	0.72	0.28	0.38	1.60	1.39	-0.8	1.4	2.0	0.8	1.40	0.6	3	6	68	3	11	8	2	19
223	7.5	0.21	0.18	0.19	1.08	1.04	2.1	2.4	2.6	2.3	0.25	2.3	1	4	76	8	9	9	3	17
224	6.0	3.5	0.43	0.80	2.85	2.35	-2.5	0.3	1.5	-0.2	2.00	-0.5	2	8	64	3	17	8	4	19
226	8.0	5.8	0.98	2.4	2.43	0.98	-2.8	-1.3	1.1	-1.0	1.95	-0.8	10	14	55	1	16	15	1	20

X-ray Mineral Percentages; Optical Petrography, Grain Types, Percentages

Station	Mica	Chlorite	Quartz	Orthoclase	Plagioclase	Calcite	Dolomite	Phyllosilicates	Feldspars	Carbonates	Quartz 1	Quartz 2	Quartz 3	Quartz 4	Quartz 5	Quartz 6	Quartz 7
164	25	32	33	2	8	0	0	57	10	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
164-A	24	35	34	2	5	0	0	59	7	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
165	2	4	86	1	2	3	2	6	3	5	23.5	3.8	0.6	0.3	0.6	0.0	33.9
166	1	4	87	1	3	3	1	5	4	4	18.9	1.6	0.0	0.0	0.0	0.0	41.8
167	13	19	57	2	5	3	1	32	7	4	18.4	1.4	2.3	0.3	1.4	0.9	27.0
168	1	3	84	3	6	2	1	4	9	3	12.7	2.5	1.0	0.0	0.6	0.0	43.1
169	3	6	78	5	6	1	1	9	11	2	21.0	2.4	1.5	0.3	0.9	0.6	32.2
170	1	3	87	3	3	2	1	4	6	3	22.2	0.3	0.9	0.0	1.2	0.6	38.5
171	4	10	72	2	6	5	1	14	8	6	5.1	0.0	0.0	0.0	0.0	0.0	19.0
172	4	7	81	2	3	2	1	11	5	3	13.6	1.5	0.9	0.0	0.9	0.0	38.6
173	3	6	80	3	4	3	1	9	7	4	15.4	0.6	0.3	0.0	0.3	0.6	37.2
174	5	6	76	4	5	3	1	11	9	4	17.0	0.6	0.6	0.0	0.9	1.2	36.6
175	2	4	80	5	5	3	1	6	10	4	21.0	2.5	1.9	0.6	0.0	0.0	34.4
176	2	5	82	3	4	3	1	7	7	4	28.0	0.6	0.6	0.0	2.1	1.5	41.0
177	2	4	83	3	4	3	1	6	7	4	34.8	0.6	1.2	1.2	3.1	0.6	22.2
178	21	27	42	1	9	0	0	48	10	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
179	24	32	34	2	8	0	0	56	10	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
180	13	24	50	0	9	4	0	37	9	4	0.0	0.0	0.0	0.0	0.0	0.7	0.7
181	1	1	86	4	3	4	1	2	7	5	22.4	3.0	0.6	0.0	0.6	0.9	29.8
190	11	18	46	1	4	19	1	29	5	20	28.6	3.9	0.9	0.9	2.7	0.6	15.8
191	7	11	69	1	3	8	1	18	4	9	11.6	1.2	0.0	0.6	0.6	0.9	27.4
192	5	8	67	1	4	14	1	13	5	15	26.5	1.5	1.9	0.6	0.0	0.6	23.1
193	1	2	83	5	3	5	1	3	8	6	26.6	2.3	1.6	0.0	1.6	0.3	30.2
194	1	3	81	3	4	7	1	4	7	8	22.5	1.9	0.3	0.9	0.9	0.9	35.0
195	3	3	77	3	6	7	1	6	9	8	19.1	1.2	1.8	0.3	1.8	1.5	34.6
196	5	11	55	3	12	12	2	16	15	14	0.0	0.0	1.7	0.0	1.7	0.0	1.7
197	2	3	83	2	5	4	1	5	7	5	24.8	2.9	1.2	0.9	4.1	0.6	22.8
198	3	6	78	3	4	5	1	9	7	6	22.9	1.5	0.6	0.3	1.2	0.6	33.0
199	3	4	80	5	3	4	1	7	8	5	29.6	1.8	0.9	0.6	1.2	0.6	19.6
200	4	7	75	2	3	8	1	11	5	9	16.2	0.9	0.3	0.9	1.2	0.0	28.3
201	5	9	61	1	7	16	1	14	8	17	13.3	2.3	0.0	1.5	2.0	1.7	17.3
202	3	5	70	2	6	13	1	8	8	14	24.8	2.7	0.0	0.3	1.2	0.3	20.5
203	3	4	80	2	3	7	1	7	5	8	13.3	3.2	0.3	0.3	2.9	0.9	24.8
207	1	3	82	5	3	5	1	4	8	6	27.4	2.6	0.9	1.2	0.6	0.3	24.5
209	1	2	87	2	2	5	1	3	4	6	13.0	0.0	0.3	1.0	1.5	1.0	38.0
210	2	4	81	2	4	6	1	6	6	7	18.5	0.9	0.9	0.9	0.9	1.8	25.6
215	11	16	50	1	13	8	1	27	14	9	17.9	0.6	1.2	0.0	0.9	0.9	23.9
217	2	2	83	3	3	5	2	4	6	7	16.7	1.8	0.6	0.3	1.5	1.2	29.0
218	1	3	87	1	3	4	1	4	4	5	18.6	4.2	0.9	0.3	0.9	0.3	26.7
219	1	2	80	6	5	5	1	3	11	6	31.0	3.2	1.6	0.3	3.2	0.0	18.2
220	2	2	82	3	4	6	1	4	7	7	29.6	4.2	2.4	0.6	1.8	0.6	18.7
221	4	3	78	5	6	3	1	7	11	4	29.8	5.8	0.6	0.9	3.0	1.5	16.7
222	3	6	77	2	7	4	1	9	9	5	22.0	2.9	0.3	0.0	2.3	0.7	28.5
223	1	2	82	4	5	5	1	3	9	6	35.3	2.5	1.2	0.3	0.6	0.6	21.0
224	2	5	75	2	10	5	1	7	12	6	16.0	1.5	0.6	0.3	0.3	1.7	25.2
226	11	8	61	1	9	9	1	19	10	10	22.4	1.5	0.3	0.9	1.5	0.9	26.2

Optical Petrography, Grain Types, Percentages (continued); Chemical Elements, Spectrographic

Station	Quartz 8	Quartz 9	Quartz 10	Quartz 11	Quartz 12	Quartz 13	Quartz 14	Quartz 15	Quartz 16	Carbonates	Arenites	Shales-slate	Crystallines	Chert	Feldspars	Aluminium	Boron	Barium	Calcium
164	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	5.6	93.1	0.3	0.0	0.3	18.2	75	560	0.13
164-A	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	1.6	97.8	0.0	0.0	0.0	23.0	82	480	0.10
165	9.7	4.4	2.2	2.5	1.0	0.3	0.6	0.0	0.0	1.2	7.2	4.7	0.3	0.3	2.9	2.9	59	100	2.32
166	9.4	4.1	3.1	3.8	0.3	0.6	0.3	0.3	0.6	0.9	5.9	4.7	0.6	0.3	2.8	2.6	23	75	2.16
167	7.0	4.4	2.6	2.3	0.9	0.3	0.3	0.6	0.3	2.6	8.8	13.4	0.9	0.6	3.3	11.4	44	410	2.28
168	14.0	5.1	1.6	4.5	1.0	0.3	0.3	0.0	0.6	0.0	3.5	4.1	0.6	0.3	4.2	2.1	34	150	0.79
169	5.8	3.3	1.8	6.7	1.2	0.3	0.0	0.6	0.6	0.3	5.4	11.5	0.3	0.9	2.4	3.3	30	150	0.52
170	6.6	2.5	2.8	3.8	2.2	0.3	0.0	0.0	0.3	1.5	6.3	4.4	0.0	1.2	4.4	2.4	42	10	2.00
171	7.7	2.5	1.5	5.1	2.5	0.5	0.0	0.0	0.5	12.3	24.5	13.3	1.0	2.5	2.0	7.1	28	170	4.65
172	12.0	5.2	3.4	2.2	0.9	0.3	0.6	0.0	0.0	0.9	5.9	9.3	0.6	0.0	3.2	3.3	36	110	1.25
173	11.2	7.1	1.5	2.5	1.2	0.0	0.0	0.3	0.3	0.3	5.6	9.6	0.0	0.6	5.4	3.4	33	50	1.76
174	11.9	3.7	1.2	2.1	2.4	0.3	0.6	0.9	0.6	1.2	4.0	10.6	0.6	0.9	2.1	3.9	32	110	1.80
175	11.2	6.6	2.5	1.9	0.9	0.3	0.3	0.0	0.3	0.6	5.6	5.0	0.9	0.6	2.9	2.9	26	70	2.35
176	8.9	0.6	2.1	2.8	0.9	0.3	1.2	0.0	0.3	1.5	2.8	1.8	0.3	0.9	1.8	2.9	37	100	1.43
177	2.5	4.9	1.8	2.1	0.9	0.9	0.3	0.9	0.9	2.4	6.2	3.4	4.0	0.0	5.7	3.3	21	45	2.07
178	1.0	0.0	2.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	16.6	77.4	1.0	0.0	0.0	13.6	57	300	0.08
179	0.0	0.0	3.2	0.0	0.6	0.0	0.0	0.0	0.0	0.0	20.1	76.1	0.0	0.0	0.0	21.4	61	540	0.07
180	0.7	1.5	7.4	3.7	8.2	0.0	0.0	1.5	0.0	5.2	46.0	20.0	2.2	1.5	2.2	12.4	38	185	2.65
181	15.8	3.6	4.2	1.2	1.5	1.2	0.3	1.2	0.3	2.7	2.7	1.5	0.0	0.6	5.4	2.2	41	100	2.63
190	7.6	2.7	2.7	0.3	0.6	0.9	0.6	0.3	0.0	11.2	4.9	9.7	0.0	0.6	4.5	11.4	47	300	9.00
191	8.9	0.9	3.6	6.2	2.7	0.0	2.4	0.3	0.0	4.8	7.1	14.9	3.3	0.3	2.4	6.8	36	240	3.75
192	8.7	4.3	3.4	0.9	0.6	1.3	0.6	0.3	0.3	6.8	5.9	9.4	0.3	0.3	2.7	5.4	32	370	4.95
193	13.3	4.9	1.9	3.9	1.9	1.0	1.9	0.0	0.6	2.6	1.3	2.3	0.0	0.3	1.5	3.0	30	125	3.14
194	10.4	0.6	2.5	2.8	1.3	0.0	1.6	0.3	0.0	2.5	5.4	3.5	3.5	0.3	2.9	3.1	30	180	3.25
195	10.0	4.8	3.9	3.3	2.7	1.5	0.6	0.3	0.3	2.7	2.7	3.0	0.9	0.0	3.3	3.0	28	120	3.50
196	0.0	1.7	5.1	1.7	5.1	0.0	0.0	0.0	0.0	16.9	27.1	22.0	15.2	0.0	0.1	10.5	25	240	5.10
197	10.6	1.8	1.8	1.8	0.9	1.2	0.6	1.8	0.6	3.0	8.3	4.1	1.2	0.3	4.7	3.4	26	44	2.92
198	6.8	1.2	3.3	1.5	1.2	1.2	0.9	0.9	0.6	2.4	5.3	5.6	3.9	0.0	5.1	3.9	31	150	2.50
199	8.0	2.4	3.3	0.9	2.1	1.5	1.5	0.0	1.2	2.7	7.1	7.4	3.3	0.0	4.3	3.5	31	75	2.31
200	10.3	1.8	3.7	1.2	0.6	1.2	2.1	0.9	1.5	4.4	9.3	4.7	5.0	0.9	4.6	5.1	31	135	4.85
201	6.4	2.6	4.1	1.2	0.6	0.3	3.3	1.2	0.0	10.5	12.0	14.0	2.6	0.0	3.1	7.0	35	240	8.12
202	9.6	2.7	4.8	2.4	1.5	0.9	2.1	0.9	0.9	6.6	9.0	4.2	1.5	0.0	3.1	4.2	29	260	4.89
203	8.9	4.1	6.8	1.2	0.9	0.6	2.1	3.3	0.6	7.7	7.7	4.7	1.5	0.3	3.9	3.1	40	135	4.20
207	6.4	3.5	1.4	1.2	0.9	1.2	0.6	1.5	0.3	3.5	10.5	7.3	0.3	0.0	3.9	3.0	42	123	2.32
209	3.8	5.0	2.5	2.8	1.9	1.6	1.3	2.5	1.0	3.1	11.0	3.8	2.2	0.3	2.4	2.9	27	30	2.50
210	7.9	2.7	4.2	1.5	0.3	0.9	0.6	1.2	0.3	5.1	14.9	7.6	0.9	0.0	2.4	3.4	26	100	3.16
215	4.8	3.6	3.3	3.0	1.5	0.9	0.6	0.6	0.3	10.4	11.6	6.0	3.9	0.3	3.8	12.3	22	350	5.00
217	13.4	4.5	1.8	1.8	0.9	2.1	1.2	0.3	0.9	1.8	9.9	4.2	1.8	0.3	4.0	3.4	34	125	2.43
218	6.6	3.9	1.8	2.1	3.0	1.8	0.9	1.5	0.9	3.6	7.8	9.9	1.5	0.0	2.8	2.9	31	160	1.03
219	7.7	1.9	1.6	2.2	0.0	1.0	2.5	1.0	0.3	3.2	6.4	5.4	1.3	0.0	8.0	4.1	54	275	2.98
220	7.8	4.2	0.6	3.0	0.6	3.3	1.2	1.8	0.3	3.3	5.1	5.1	0.9	0.0	4.9	4.2	29	205	3.13
221	6.4	3.0	2.1	1.5	0.0	0.6	0.6	0.6	1.2	4.0	12.1	4.5	0.0	0.0	5.1	4.8	22	170	3.20
222	5.6	2.3	1.3	4.9	1.3	1.0	1.0	0.7	0.0	3.6	11.5	6.6	1.3	0.3	1.9	3.4	20	90	2.22
223	8.1	1.9	0.9	1.5	1.2	0.3	0.9	1.5	0.3	3.1	6.5	6.5	0.6	0.0	5.3	2.9	24	90	2.67
224	9.6	3.5	3.5	3.5	4.1	0.6	0.6	0.6	0.0	5.3	12.2	5.5	3.8	0.0	2.6	4.8	19	170	2.52
226	6.8	3.1	1.2	2.8	1.5	0.6	2.1	0.6	0.0	3.1	14.8	4.0	0.6	0.0	5.1	8.0	27	290	3.38

Chemical Elements, Spectrographic (continued)

Station	Cobalt	Chromium	Copper	Iron	Gallium	Potassium	Magnesium	Manganese	Sodium	Nickel	Lead	Scandium	Strontium	Titanium	Vanadium	Zirconium
164	36.0	105	48.0	7.52	29.3	1.96	0.72	820	1.17	56.0	680	30.6	104	5150	109	106
164-A	34.0	106	50.0	7.15	28.7	1.67	1.30	1030	1.07	56.0	63	31.0	105	5250	112	120
165	5.8	58	2.8	2.85	2.8	0.23	0.45	450	0.15	16.0	17	8.0	115	2800	55	266
166	4.1	19	2.7	2.10	2.4	0.21	0.28	300	0.17	11.8	11	3.8	118	890	37	276
167	12.7	65	24.8	4.41	14.8	0.80	0.70	600	0.76	33.0	48	22.0	162	3650	85	120
168	3.8	38	2.1	1.80	2.3	0.21	0.25	280	0.09	11.8	13	4.7	94	2100	38	220
169	5.9	24	3.2	2.31	3.9	0.40	0.31	288	0.40	16.0	22	5.6	77	1650	45	85
170	4.1	46	2.9	1.74	1.7	0.25	0.35	305	0.24	11.8	6	5.6	78	2450	43	138
171	8.2	36	14.4	3.55	7.0	0.65	0.46	520	0.66	25.0	23	7.9	257	1620	57	83
172	6.1	62	4.3	2.98	3.6	0.40	0.28	450	0.28	19.0	14	8.1	78	2800	58	630
173	5.6	42	3.5	2.33	3.2	0.34	0.29	410	0.34	16.5	10	6.7	73	2100	49	218
174	6.1	29	5.3	2.40	4.0	0.39	0.30	320	0.36	16.0	13	7.0	87	2050	51	87
175	4.5	32	2.1	1.80	2.6	0.28	0.31	330	0.34	15.5	7	6.1	115	2000	43	840
176	5.3	44	4.7	2.40	3.1	0.34	0.34	380	0.36	18.0	9	7.2	86	2250	53	155
177	3.8	18	2.0	1.41	1.7	0.21	0.33	305	0.25	8.6	5	3.9	106	1300	37	120
178	20.7	85	90.0	6.30	22.8	1.64	0.97	670	1.10	46.0	186	24.2	82	4600	98	140
179	17.5	102	43.0	7.05	25.0	1.59	1.10	500	1.04	49.0	167	34.0	100	5000	113	139
180	13.3	57	22.8	5.90	15.0	1.18	0.93	490	1.08	40.0	11	20.7	127	3650	76	179
181	3.4	62	11.2	1.70	1.9	0.35	0.32	310	0.15	11.6	4	4.4	122	1850	47	620
190	7.7	69	37.0	4.15	11.2	1.59	1.64	330	2.00	27.0	27	13.0	450	2760	84	275
191	7.8	47	24.0	3.76	7.9	0.62	0.41	400	0.61	25.5	15	8.4	158	1800	66	51
192	6.6	43	32.0	3.15	8.0	0.68	0.54	400	0.77	22.8	21	7.4	210	1020	44	82
193	4.0	22	9.6	1.90	2.5	0.33	0.41	325	0.27	11.0	8	4.2	168	1200	48	127
194	5.7	34	11.6	2.63	2.7	0.28	0.42	435	0.25	16.2	13	4.6	160	1330	35	79
195	4.9	26	29.0	2.20	3.0	0.25	0.36	365	0.43	13.4	13	4.3	215	1120	50	67
196	8.6	43	19.0	3.39	10.0	1.03	0.85	780	1.13	25.7	9	13.3	198	1700	55	118
197	5.1	19	15.1	2.07	2.7	0.26	0.38	320	0.36	12.0	22	4.4	157	1130	38	82
198	6.2	29	20.3	2.76	4.9	0.54	0.33	350	0.58	17.0	20	6.8	121	1920	55	143
199	4.9	52	8.8	2.21	3.3	0.33	0.35	335	0.41	16.5	7	7.7	115	2380	50	114
200	6.4	29	12.3	2.73	4.7	0.30	0.50	580	0.49	18.0	20	5.6	271	1300	52	92
201	6.1	59	19.3	2.80	6.8	0.56	0.72	460	0.69	21.8	23	7.6	460	1420	48	90
202	5.6	75	10.7	2.72	4.6	0.46	0.50	370	0.52	16.0	21	4.8	270	1470	52	128
203	5.1	120	5.1	2.98	2.7	0.26	0.42	470	0.29	18.0	8	7.7	214	2250	60	970
207	5.6	61	8.1	2.59	2.9	0.28	0.36	480	0.43	16.4	18	7.3	111	2150	55	740
209	4.3	21	5.0	1.60	1.7	0.21	0.37	370	0.21	9.7	6	4.0	113	1200	38	75
210	6.1	45	21.5	2.85	3.9	0.29	0.45	390	0.47	17.8	16	5.9	148	1430	52	94
215	7.2	41	12.6	3.68	11.6	1.12	0.61	615	1.14	19.8	13	15.0	345	2170	57	92
217	5.3	51	8.2	2.44	3.0	0.31	0.39	495	0.40	12.8	24	5.3	122	1820	55	350
218	5.7	75	4.0	2.68	3.0	0.27	0.39	490	0.50	12.4	17	5.9	95	1800	57	178
219	4.2	93	5.4	2.79	3.6	0.41	0.44	585	0.40	21.6	17	9.0	134	3730	64	2000
220	3.9	23	6.9	1.94	2.8	0.36	0.44	430	0.40	10.2	16	5.1	149	1850	45	172
221	4.4	38	21.8	2.49	4.3	0.41	0.42	390	0.53	15.0	17	6.8	147	2060	58	323
222	7.3	34	7.0	3.08	4.3	0.39	0.35	550	0.40	15.6	11	7.0	120	1300	55	86
223	4.7	19	7.5	1.71	2.3	0.30	0.35	360	0.34	10.4	12	3.7	140	1030	44	109
224	7.6	31	5.8	3.13	5.0	0.51	0.40	510	0.63	17.8	7	7.5	96	1690	51	123
226	9.2	40	15.4	4.56	8.4	0.65	0.45	670	0.84	22.8	20	16.7	120	3000	86	141

TABLE VII
(St. 227–277)

Textural Statistics; Basic X-ray Diffractogram Values

Station	Depth	Q1	Q3	Md	So	Sk	Ø16	ØM50	Ø84	ØMz	Øσg	ØMI	Mica	Chlorite	Quartz	Orthoclase	Plagioclase	Calcite	Dolomite	Background
227	8.5	0.28	0.20	0.24	1.18	0.97	1.7	2.1	2.4	2.1	0.35	2.0	3	5	76	6	7	9	2	17
229	8.0	0.24	0.20	0.22	1.09	0.99	1.9	2.2	2.5	2.2	0.30	2.2	2	3	80	3	9	7	3	16
230	10.0	0.17	0.14	0.15	1.10	1.05	2.4	2.7	3.1	2.7	0.35	2.7	2	3	80	4	7	9	3	17
231	8.0	0.34	0.25	0.29	1.08	1.01	1.4	1.8	2.2	1.8	0.40	1.8	2	3	82	7	7	9	3	16
232	5.0	0.68	0.25	0.31	1.65	1.77	-1.5	1.7	2.2	0.8	1.85	0.3	4	10	67	4	13	8	0	19
233	4.5	0.26	0.17	0.21	1.23	1.00	1.8	2.3	2.7	2.2	0.45	2.2	1	4	79	2	5	8	3	17
234	5.0	0.26	0.15	0.19	1.31	1.07	1.8	2.4	2.8	2.3	0.50	2.3	1	4	79	8	7	7	3	17
235	4.5	0.27	0.17	0.22	1.25	0.94	1.8	2.2	2.7	2.2	0.45	2.2	2	3	78	6	6	7	4	17
236	4.5	0.27	0.16	0.20	1.30	1.08	1.8	2.3	2.8	2.3	0.50	2.3	2	4	76	5	10	8	2	17
237	4.0	0.20	0.13	0.15	1.24	1.15	2.1	2.7	2.9	2.5	0.40	2.5	2	3	71	6	6	9	4	18
238	3.0	0.66	0.16	0.22	2.03	2.18	-0.1	2.2	2.8	1.6	1.45	1.3	1	3	56	5	4	11	1	17
239	5.0	0.22	0.15	0.18	1.21	1.01	1.5	2.5	2.9	2.3	0.70	2.2	1	3	67	5	9	7	4	17
240	5.0	0.18	0.14	0.16	1.13	0.98	2.3	2.6	3.0	2.6	0.35	2.6	1	4	51	6	4	7	8	24
241	4.5	0.26	0.18	0.21	1.20	1.06	1.7	2.3	2.6	2.2	0.45	2.1	2	5	74	5	11	7	2	17
242	5.5	0.33	0.23	0.28	1.20	0.97	1.5	1.8	2.3	1.8	0.40	1.9	2	5	78	4	6	8	2	17
243	5.5	0.26	0.18	0.22	1.20	0.96	1.8	2.2	2.7	2.2	0.45	2.2	2	3	81	7	7	7	3	17
244	6.0	0.21	0.17	0.18	1.11	1.10	2.1	2.5	2.7	2.4	0.30	2.4	2	5	77	5	9	10	3	17
245	7.0	0.21	0.18	0.19	1.07	1.04	2.1	2.4	2.7	2.4	0.30	2.4	2	4	72	7	6	8	4	17
246	8.5	0.25	0.18	0.21	1.18	1.02	1.8	2.3	2.6	2.2	0.40	2.2	1	3	75	4	6	11	3	17
247	8.0	2.9	0.29	0.58	3.16	2.50	-2.4	0.8	2.1	0.2	2.25	-0.1	4	8	61	3	11	15	4	20
250	9.5	1.0	0.35	0.57	1.69	1.07	-0.7	0.8	1.8	0.6	1.25	0.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
252	9.0	0.27	0.17	0.22	1.26	0.94	1.7	2.2	2.7	2.2	0.50	2.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
253	10.0	0.40	0.22	0.30	1.35	0.98	1.1	1.7	2.4	1.7	0.65	1.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
254	10.5	0.56	0.28	0.41	1.41	0.93	0.5	1.3	2.1	1.3	0.80	1.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
256	11.5	1.3	0.27	0.33	2.19	3.22	-2.1	1.6	2.0	0.5	2.05	-0.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
257	12.0	0.36	0.22	0.27	1.27	1.08	1.2	1.9	2.4	1.8	0.60	1.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
258	12.5	0.47	0.25	0.33	1.34	1.08	0.0	1.6	2.2	1.2	1.10	1.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
259	12.5	0.35	0.21	0.28	1.29	0.93	1.3	1.8	2.5	1.8	0.60	1.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
260	12.0	0.52	0.31	0.41	1.29	0.95	0.7	1.3	1.9	1.3	0.60	1.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
261	11.0	0.43	0.18	0.23	1.54	1.46	0.4	2.1	2.6	1.7	1.10	1.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
262	9.0	1.1	0.25	0.47	2.10	1.24	-2.0	1.1	2.4	0.5	2.20	0.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
263	7.0	0.30	0.19	0.23	1.25	1.07	1.4	2.1	2.5	2.0	0.55	1.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
264	6.0	0.28	0.18	0.23	1.24	0.95	1.7	2.1	2.6	2.1	0.45	2.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
265	6.0	0.28	0.21	0.24	1.15	1.02	1.8	2.1	2.4	2.1	0.30	2.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
267	0	2.2	0.30	0.78	2.71	1.08	-1.8	0.4	2.0	0.2	1.90	0.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
268	0	7.6	1.5	3.0	2.25	1.26	-3.3	-1.6	-0.3	-1.7	1.80	-1.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
269	12.0	0.24	0.18	0.21	1.15	0.99	1.9	2.3	2.6	2.2	0.35	2.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
270	12.0	0.47	0.33	0.40	1.19	0.97	1.0	1.3	1.8	1.3	0.40	1.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
271	10.0	0.33	0.25	0.29	1.15	0.98	1.4	1.8	2.2	1.8	0.40	1.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
272	8.0	3.8	0.74	1.4	2.26	1.43	-2.6	-0.5	0.8	-0.8	1.70	-0.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
273	8.5	7.8	0.39	1.8	4.46	0.94	-3.4	-0.9	1.8	-0.8	2.60	-0.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
274	8.5	1.9	0.48	0.68	1.99	1.92	-1.6	0.6	1.3	0.1	1.45	-0.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
275	11.0	0.23	0.18	0.20	1.13	1.03	1.9	2.3	2.6	2.2	0.35	2.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
276	6.5	0.22	0.15	0.19	1.21	0.91	2.1	2.4	2.9	2.4	0.40	2.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
277	5.0	0.16	0.13	0.15	1.11	0.92	2.5	2.7	3.0	2.7	0.25	2.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

X-ray Mineral Percentages; Optical Petrography, Grain Types, Percentages

Station	Mica	Chlorite	Quartz	Orthoclase	Plagioclase	Calcite	Dolomite	Phyllosilicates	Feldspars	Carbonates	Quartz 1	Quartz 2	Quartz 3	Quartz 4	Quartz 5	Quartz 6	Quartz 7	Quartz 8	Quartz 9	Quartz 10	Quartz 11	Quartz 12	Quartz 13	Quartz 14	Quartz 15	Quartz 16	Carbonates	Arenites	Shales-slate	Crystallines	Chert	Feldspars
227	3	3	81	3	4	5	1	6	7	6	30.4	4.8	2.4	0.6	1.5	0.3	18.3	9.3	2.1	0.6	2.4	1.5	0.9	0.6	0.6	0.9	4.8	5.7	6.9	1.5	0.0	3.9
229	2	2	84	2	5	4	1	4	7	5	16.2	0.9	0.0	1.2	1.2	0.3	31.0	15.0	4.2	1.2	2.1	2.4	0.9	2.1	0.6	0.3	4.5	5.4	3.3	1.8	0.0	5.4
230	2	2	84	2	4	5	1	4	6	6	22.4	3.5	2.9	0.6	1.9	1.0	29.0	9.3	3.2	1.6	1.6	1.3	0.3	2.2	0.9	1.0	3.5	4.8	5.1	0.0	0.0	3.9
231	2	2	82	4	4	5	1	4	8	6	25.0	1.2	0.9	0.9	1.2	0.3	26.6	9.7	2.4	5.7	1.2	1.5	0.0	1.5	0.6	0.3	4.5	9.4	3.0	1.2	0.0	2.9
232	5	6	75	2	8	4	0	11	10	4	19.7	2.3	2.6	0.0	1.0	0.0	29.1	8.4	6.5	0.0	1.9	1.9	0.0	1.0	0.9	0.6	4.2	7.8	6.5	0.6	0.0	5.0
233	1	2	87	1	3	5	1	3	4	6	21.0	2.4	2.4	0.0	3.0	1.2	21.2	11.5	7.6	1.8	1.5	1.2	1.2	0.0	0.0	0.9	4.5	3.3	2.4	2.7	0.3	9.9
234	1	2	84	4	4	4	1	3	8	5	34.1	4.8	1.3	0.0	1.6	0.3	26.0	4.8	3.5	0.6	2.6	0.6	0.0	1.0	0.3	0.0	1.0	4.5	3.5	1.3	0.0	8.2
235	2	2	85	3	3	4	1	4	6	5	34.2	2.3	3.5	1.2	3.0	1.7	19.7	5.0	5.6	1.5	0.3	0.9	1.2	1.8	0.6	0.9	1.7	6.5	2.3	1.2	0.0	4.9
236	2	2	82	3	6	4	1	4	9	5	36.2	5.9	4.6	1.8	2.2	1.8	10.0	3.7	6.8	1.2	1.8	0.3	0.6	0.6	0.0	0.3	2.5	6.8	5.0	0.6	0.0	7.3
237	2	2	82	4	4	5	1	4	8	6	33.8	4.0	5.8	0.6	1.8	0.6	12.9	4.0	7.4	0.0	1.5	1.8	0.6	0.3	0.0	0.3	4.0	5.2	4.9	2.7	0.3	7.5
238	2	3	79	4	3	8	1	5	7	9	30.7	4.5	7.3	0.3	1.2	0.3	17.3	4.5	8.8	0.3	0.6	0.6	0.3	1.2	0.3	0.9	3.0	6.4	2.4	0.6	0.0	8.5
239	1	2	81	4	6	5	1	3	10	6	33.7	4.3	10.0	0.9	0.6	1.5	12.3	2.1	7.4	1.2	0.3	0.6	2.4	0.0	0.9	0.0	1.8	6.5	3.4	0.6	0.0	9.5
240	2	3	77	5	3	6	4	5	8	10	22.8	5.3	0.9	0.6	1.9	1.6	21.2	8.5	5.9	0.3	1.9	0.6	1.2	0.6	0.6	0.9	3.7	1.9	3.1	2.2	0.0	14.3
241	2	3	80	3	7	4	1	5	10	5	19.7	2.1	0.3	0.3	2.1	0.3	26.4	9.4	7.6	0.6	2.1	1.5	0.9	0.9	1.8	0.9	3.9	5.4	4.5	2.1	0.6	6.6
242	2	3	84	2	3	5	1	5	5	6	20.5	3.0	1.2	0.3	1.2	0.6	23.8	8.6	7.5	1.8	4.1	1.8	0.3	0.6	0.6	0.6	3.6	3.9	8.0	3.0	0.0	5.0
243	2	2	83	4	4	4	1	4	8	5	35.4	2.7	2.4	0.0	0.9	0.0	20.0	8.0	5.0	1.2	2.7	0.9	0.6	0.6	1.5	0.0	3.3	5.4	2.4	1.5	0.3	5.2
244	2	3	81	3	5	5	1	5	8	6	31.0	2.7	2.7	0.3	1.5	0.9	21.2	6.0	8.2	1.2	1.2	1.5	0.3	0.3	1.2	0.6	3.0	4.3	5.2	0.9	0.6	5.2
245	2	2	82	4	4	5	1	4	8	6	39.0	1.8	4.5	0.0	2.4	0.3	15.4	3.3	4.8	0.9	1.5	1.2	0.0	0.3	0.9	0.0	4.8	6.0	3.3	1.8	0.6	7.2
246	1	2	83	2	4	7	1	3	6	8	26.0	5.2	2.7	0.9	1.5	0.9	22.3	7.9	7.9	0.9	0.9	0.3	0.0	0.6	0.6	0.6	5.7	4.3	4.6	1.2	0.3	4.7
247	5	5	71	2	7	9	1	10	9	10	27.4	1.5	3.7	0.6	1.5	0.6	20.7	2.7	5.2	0.3	1.8	3.0	0.3	1.2	0.6	0.3	8.8	5.2	5.5	2.7	0.3	5.1
250	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	23.2	6.6	5.4	0.6	1.8	2.4	9.7	5.7	3.0	0.6	0.6	0.9	0.6	0.0	1.2	0.3	9.3	9.7	3.6	3.0	0.9	2.1
252	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	26.3	3.4	2.5	0.6	1.5	1.5	21.9	6.0	8.4	1.0	1.5	0.3	0.3	0.0	1.0	0.0	6.8	5.5	1.9	4.4	0.3	4.9
253	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	37.5	4.1	4.4	0.3	1.2	0.9	14.2	4.4	4.4	0.3	0.6	1.5	0.9	0.9	1.5	0.9	4.1	5.0	3.5	3.5	0.0	5.9
254	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	35.1	1.9	4.1	0.3	1.6	2.2	11.3	7.2	6.6	0.0	1.2	0.9	1.2	0.9	0.3	0.3	6.6	5.3	5.0	3.1	0.0	4.9
256	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	35.0	2.8	4.7	0.6	0.6	1.6	19.8	3.5	7.2	0.9	0.6	1.9	0.3	0.0	0.6	0.3	6.0	4.1	2.2	2.5	0.0	4.8
257	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	35.6	3.6	3.9	1.8	4.5	0.9	13.1	3.9	6.3	0.6	3.0	1.5	1.2	1.8	0.6	0.3	5.1	3.6	2.1	1.2	0.0	5.4
258	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	38.5	2.2	1.6	0.3	2.5	1.6	21.4	2.8	5.4	0.3	1.9	0.6	1.0	0.3	0.3	1.0	3.8	3.8	1.0	5.4	0.0	4.3
259	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	30.1	2.2	1.6	0.3	2.9	0.6	19.5	3.2	9.1	0.0	1.9	0.6	0.0	2.2	0.0	0.0	8.7	4.8	1.6	3.9	0.3	6.5
260	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	47.0	4.1	5.3	0.0	1.9	1.6	11.6	2.5	6.3	0.3	1.0	1.2	0.0	0.6	0.3	0.3	5.6	3.1	2.5	1.9	0.0	3.0
261	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	40.5	2.4	3.6	0.0	1.2	0.9	13.6	6.0	6.7	0.3	1.2	0.9	0.9	0.0	0.9	2.1	6.0	2.1	2.1	2.4	0.0	6.2
262	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	33.0	1.5	8.1	0.0	2.1	1.2	14.7	1.8	6.0	0.0	0.3	1.2	0.9	2.7	1.8	0.3	6.0	2.7	8.7	2.1	0.0	4.9
263	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	32.2	1.8	5.1	0.6	2.7	1.5	19.4	1.5	6.6	0.3	1.5	2.4	0.0	0.9	1.5	0.6	4.5	5.1	5.7	1.8	0.0	4.3
264	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	35.6	1.5	2.9	1.2	0.9	1.2	21.4	6.4	6.1	0.9	0.9	1.5	0.9	1.7	0.9	0.6	3.2	4.0	2.0	0.9	0.0	5.3
265	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	44.1	6.0	3.9	0.9	1.5	1.2	11.2	4.2	5.4	0.3	0.6	0.9	0.3	1.5	1.2	0.9	3.3	4.8	0.9	1.5	0.3	5.1
267	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	31.0	2.4	2.4	0.0	1.2	1.2	9.0	0.9	3.0	0.9	0.3	0.6	0.6	0.6	0.3	0.3	4.5	21.5	11.0	4.5	0.0	2.8
268	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	16.7	0.0	2.0	1.0	2.5	2.0	3.6	0.5	4.5	0.5	0.0	0.5	0.5	1.0	1.5	0.0	4.5	32.5	16.2	4.5	1.0	4.5
269	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	45.1	1.2	1.4	0.9	1.2	1.2	18.4	1.4	3.8	0.3	0.6	1.4	0.3	0.6	0.0	0.3	5.2	5.2	1.7	2.3	1.2	6.3
270	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	34.4	3.0	1.5	2.1	2.4	2.1	11.4	5.4	6.0	0.3	1.2	1.2	0.6	1.2	1.5	0.0	8.4	6.0	2.1	3.6	0.0	5.6
271	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	34.0	2.4	3.9	1.2	1.5	1.2	16.5	3.9	4.8	1.5	1.5	2.7	0.9	0.6	0.3	0.6	5.1	6.0	2.4	3.0	0.6	5.4
272	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	25.0	0.0	2.8	0.0	2.8	1.4	12.8	1.4	5.0	0.0	2.8	4.2	0.0	0.0	0.7	0.0	14.1	12.8	5.7	5.0	0.0	4.2
273	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	31.0	2.2	4.6	0.6	1.2	1.8	6.8	1.5	3.1	0.9	1.2	1.2	0.6	0.6	0.0	0.3	15.2	12.1	7.7	3.7	0.3	3.4
274	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	34.4	1.5	1.5	0.4	1.5	1.1	7.3	4.0	1.5	0.0	1.8	1.1	0.0	0.0	0.7	0.0	11.0	10.6	9.6	6.6	0.7	4.7
275	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	33.6	0.9	1.5	0.9	1.2	0.6	22.4	6.6	7.2	0.3	0.3	1.2	0.9	0.6	0.6	0.3	3.9	2.1	2.7	3.3	0.6	8.3
276	n.d	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	47.0	2.9	5.1	0.3	1.6	0.6	10.8	4.1	6.7	0.0	0.6	0.3	1.0	0.6	1.6	0.6	6.7	2.2	1.6	1.9	0.0	3.8
277	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	41.0	3.5	5.0	0.6	0.6	1.6	7.2	6.9	6.9	0.0	0.3	0.0	0.9	0.6	1.3	0.6	4.4	2.5	4.1	3.1	0.0	8.9

Chemical Elements, Spectrographic

Station	Aluminum	Boron	Barium	Calcium	Cobalt	Chromium	Copper	Iron	Gallium	Potassium	Magnesium	Manganese	Sodium	Nickel	Lead	Scandium	Strontium	Titanium	Vanadium	Zirconium
227	3.6	24	105	3.25	4.8	25	5.9	2.30	2.8	0.28	0.39	400	0.36	12.2	11	5.2	162	1500	51	105
229	2.2	37	75	2.25	5.5	42	8.4	2.24	2.2	0.23	0.28	440	0.33	11.6	20	4.6	106	1560	49	201
230	2.6	28	40	2.52	5.1	41	9.8	2.06	1.9	0.22	0.34	450	0.22	11.6	9	4.0	130	890	47	95
231	2.7	30	50	2.42	4.2	43	28.5	2.13	1.9	0.19	0.37	445	0.17	11.8	6	4.6	125	1220	45	153
232	5.6	31	190	3.05	6.6	48	20.4	3.40	6.3	0.52	0.43	620	0.65	16.0	11	10.8	140	2260	57	233
233	3.8	36	100	2.77	4.5	40	20.0	1.96	2.8	0.28	0.42	445	0.36	12.0	15	6.1	134	2400	46	450
234	3.0	38	110	2.17	5.4	38	7.9	2.00	2.5	0.31	0.36	480	0.33	12.1	13	5.4	108	2050	48	495
235	2.8	29	75	2.13	5.9	23	6.4	2.05	2.1	0.22	0.36	520	0.33	11.3	16	5.0	104	1620	49	195
236	2.6	29	75	2.00	5.1	34	15.5	2.15	2.2	0.35	0.31	420	0.33	10.5	11	4.9	95	1490	50	178
237	4.1	59	135	3.45	5.3	87	13.3	2.80	2.8	0.31	0.43	660	0.34	15.9	23	9.6	150	5600	69	1040
238	3.0	31	185	6.05	4.6	46	22.1	2.40	3.2	0.32	0.31	410	0.41	10.9	33	3.2	370	1600	49	262
239	3.6	52	160	3.65	5.4	50	13.0	2.85	3.4	0.29	0.38	560	0.40	29.7	25	10.2	168	4250	68	2600
240	3.8	116	340	2.86	135.0	1300	20.2	8.50	5.2	0.45	0.45	1560	0.44	145.0	25	65.0	328	24000	186	10100
241	3.5	23	100	2.50	5.4	24	5.6	2.10	3.0	0.31	0.29	370	0.46	12.7	12	5.7	133	1430	48	370
242	3.1	33	120	2.12	5.2	30	7.1	2.23	2.4	0.27	0.33	515	0.23	12.3	10	5.9	111	1660	53	285
243	2.6	30	120	2.02	5.3	22	4.3	1.95	2.0	0.28	0.31	440	0.30	10.1	14	3.7	100	1080	47	92
244	3.3	40	130	2.42	4.7	28	6.0	2.17	3.2	0.45	0.42	410	0.37	11.0	13	6.2	124	2350	50	157
245	3.2	48	160	2.30	4.3	85	4.7	2.61	3.2	0.47	0.34	500	0.38	24.2	14	9.8	116	3600	59	2300
246	4.0	34	210	3.89	4.0	57	7.7	2.38	3.3	0.47	0.46	385	0.36	13.2	11	6.3	128	2720	50	570
247	5.4	32	280	4.67	7.0	44	14.5	3.90	6.2	0.50	0.52	635	0.59	20.4	13	8.8	226	1870	59	201
250	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
252	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
253	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
254	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
256	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
257	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
258	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
259	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
260	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
261	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
262	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
263	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
264	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
265	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
267	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
268	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
269	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
270	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
271	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
272	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
273	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
274	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
275	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
276	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
277	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

PLATE 2

Fig. 1. View of Aberystwyth greywackes exposed on the shore of Cardigan Bay near Station 149. Near the match box (4·5 inches in length) there are eroded blocks of an arenite bed which are in process of being contributed to the nearby littoral sediments. Field evidence along the coast between Aberystwyth and Borth suggests that a considerable amount of such erosion takes place there.

Fig. 2. Boulder beach in the vicinity of Station 131, about 2 km. north of Sarn Bwch. Boulders have been eroded from the glacial debris here and have formed a natural rip-rap. Nevertheless, considerable quantities of sand are being eroded from the cliffs and washed past the boulders into the bay. The view is looking north. This region and the coastal section at Towyn contribute much detritus to the bay.

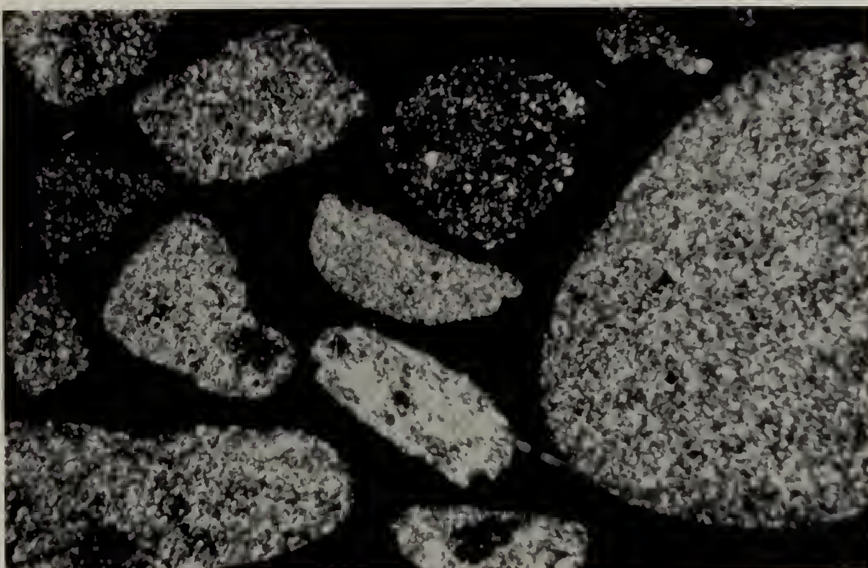
1

2

PLATE 3

Fig. 1. Thin section photomicrograph of sample from Station 162 (BM 1964, 227) near town of Machynlleth. Note that all grains are lithic fragments, primarily of slate. River deposits in the upper Afon Dyfi are all similar to this example in composition, although some local variations in texture are observed along the banks. This and subsequent Afon Dyfi samples are from sites of active transport. (Crossed nicols, × 30.)

Fig. 2. Thin section photomicrograph of sample from Station 161 (BM 1964, 226), downstream from Machynlleth. While the sediment is composed of lithic fragments resembling those at Station 162 (Pl. 3, fig. 1), there is a noticeable decrease in grain size. (Crossed nicols, × 30.)



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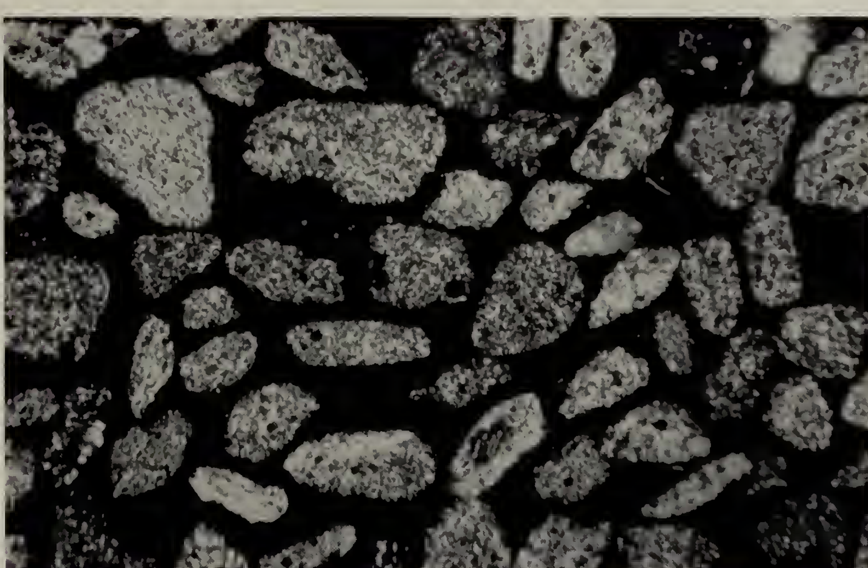
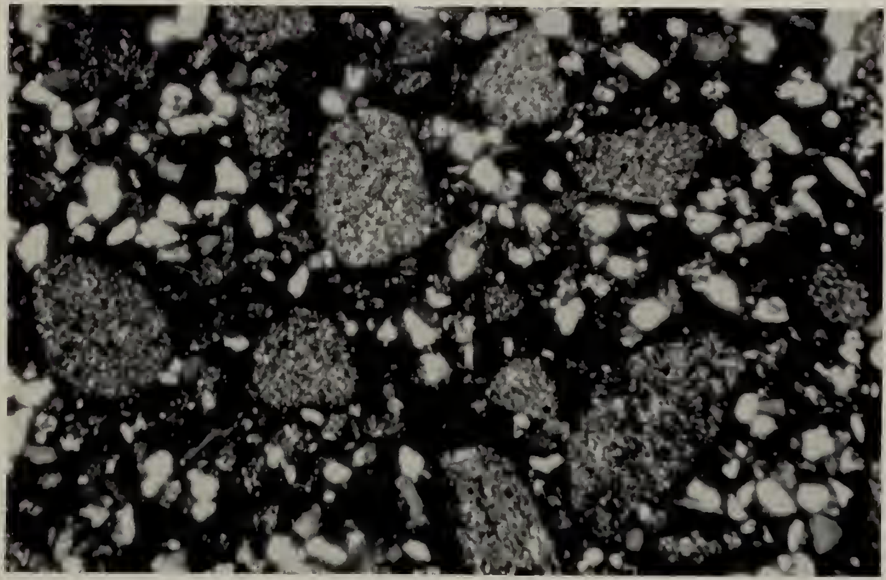


2

PLATE 4

Fig. 1. Thin section photomicrograph of sample from Station 159 (BM 1964, 224) in the " lower river–upper estuary " transition environment of sedimentation on the Afon Dyfi. Note the pronounced appearance of fine quartz sand along with the larger lithic fragments. This thin section shows the textural control of composition at this site. Since it is within tidal range, the quartz sand is presumed to be related to the estuary. (Crossed nicols, × 30).

Fig. 2. Thin section photomicrograph of sample from Station 163 (BM 1964, 228) at the head of the Dyfi estuary. Notice here that the predominant clastic is quartz sand and that lithic fragments are much subordinate. This is a " typical " estuary sand, quartzose and well sorted. (Crossed nicols, × 30.)



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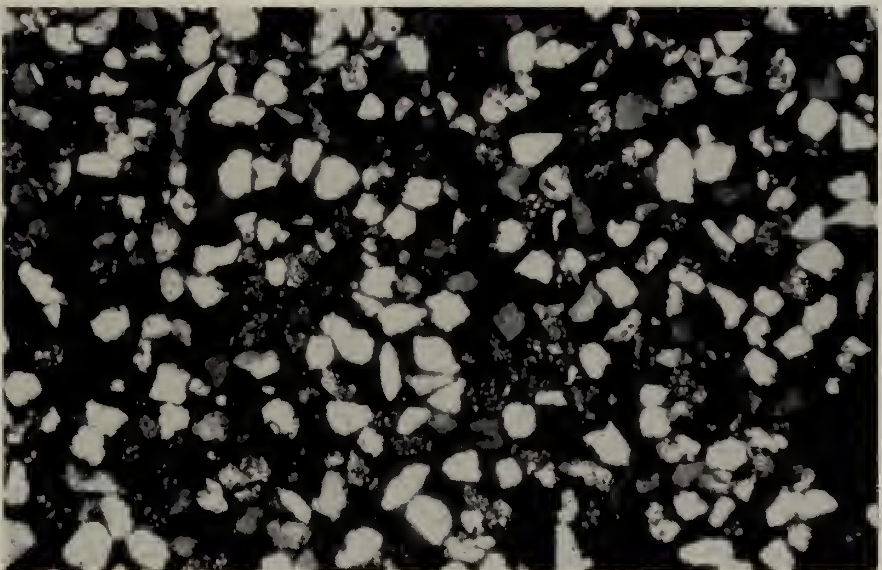
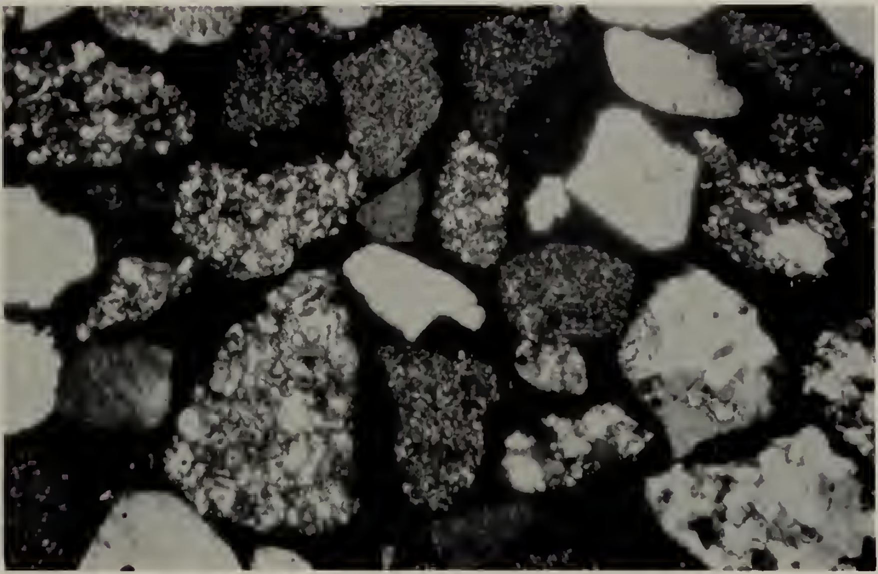


2

PLATE 5

FIG. 1. Thin section photomicrograph of sample from Station 148 (BM 1964, 212) near the point where Sarn Wallog joins the coast. Note the mixed lithic (arenites and silty shales) and quartz assemblage. This sample was collected at the base of the coastal cliffs of exposed Aberystwyth grits. The abundance of large, angular arenite fragments is suggestive of their proximity to source ; furthermore, such lithic grains are quickly reduced in size with transport in a relatively high energy zone. (Crossed nicols, × 30.)

FIG. 2. Thin section photomicrograph of sample from Station 144 (BM 1964, 208), also from the cliff-backed, littoral zone south of Borth. Notice here the similarity to Station 148 (Pl. 5, fig. 1) in grains present, i.e., a mixture of quartz and lithic types. Some of the quartz suggests affinities with vein quartz in the nearby outcrops. Regardless of local sorting, the compositional suite remains much the same as shown here, with, perhaps, a slight increase in quartz grains in the finer sediments. (Crossed nicols, × 30.)



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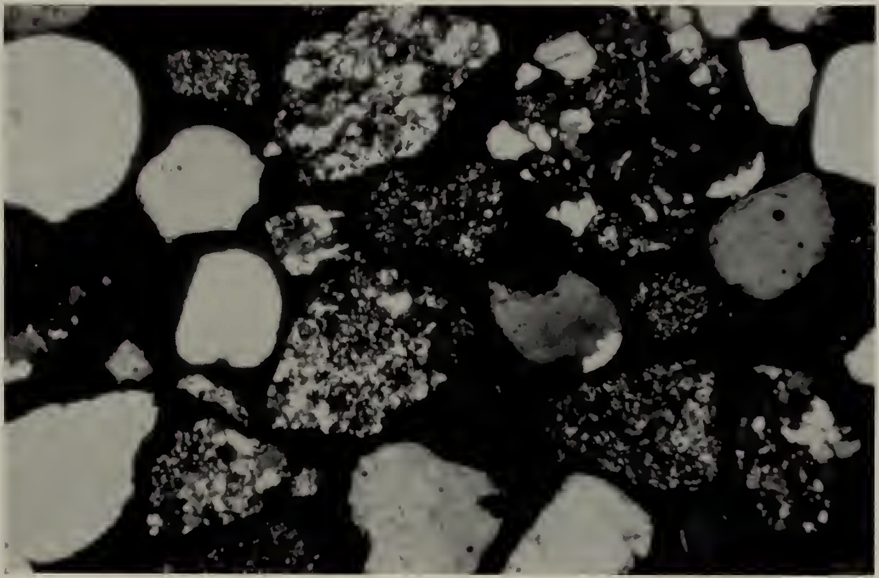

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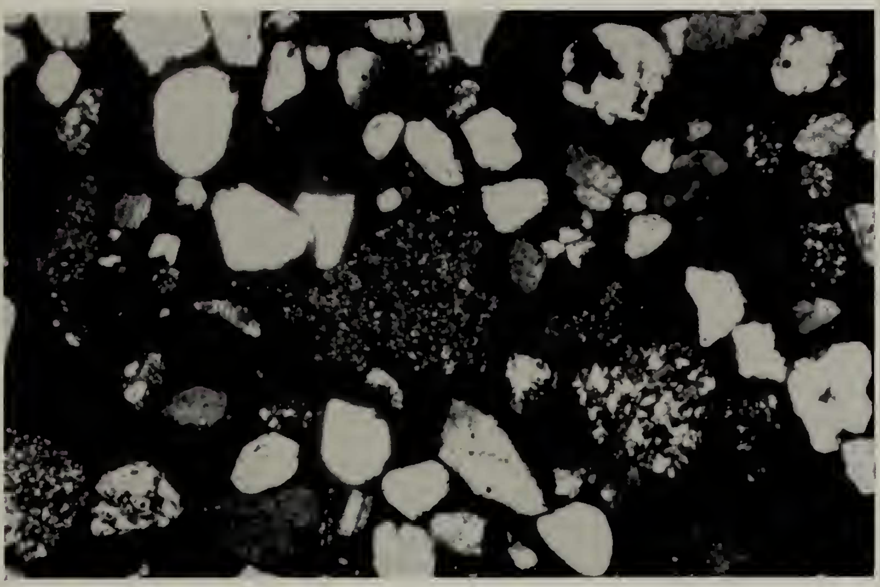
PLATE 6

FIG. 1. Thin section photomicrograph of sample from Station 150 (BM 1964, 214) collected on the south end of the beach at Borth. This sample shows the mixture of both lithic and quartz varieties in the littoral zone, an influence of local source and littoral sorting. Slate fragments in this sample resemble slate outcropping nearby; furthermore, the slate/arenite ratio of the Aberystwyth beds increases towards the north, as determined from measurements along the coast (Prof. Alan Wood, personal communication). (Crossed nicols, × 30.)

FIG. 2. Thin section photomicrograph of sample from Station 7 (BM 1964, 91), a well-sorted, sub-lithic sand offshore from Borth. Although this station is only 1·5 km. offshore, the index of sorting (std dev.: 0·15; So: 1·06) is pronounced. Lithic (arenite) fragments constitute slightly over 8% of the grains counted, as against 10·0% or over at Station 150 (Pl. 6, fig. 1) on the coast. (Crossed nicols, × 30.)



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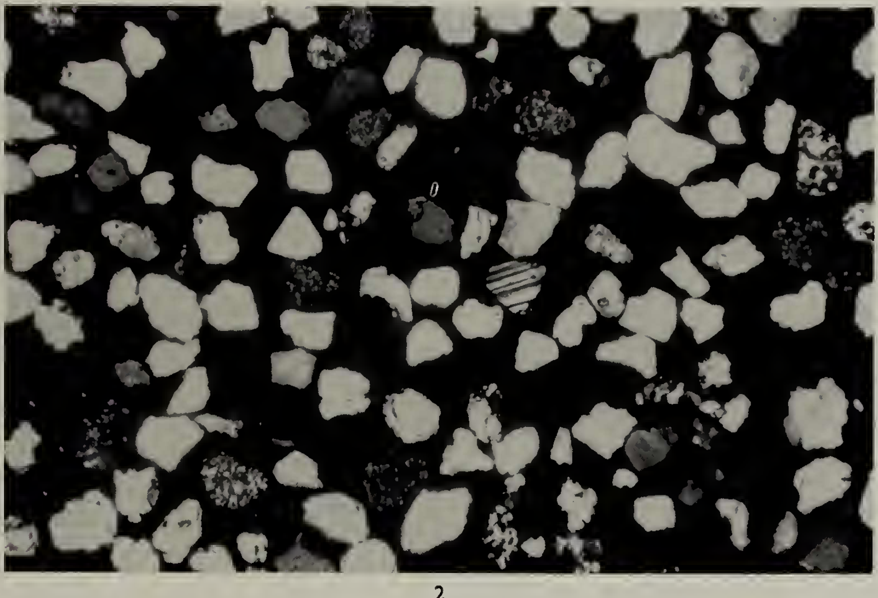

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